# CANMET

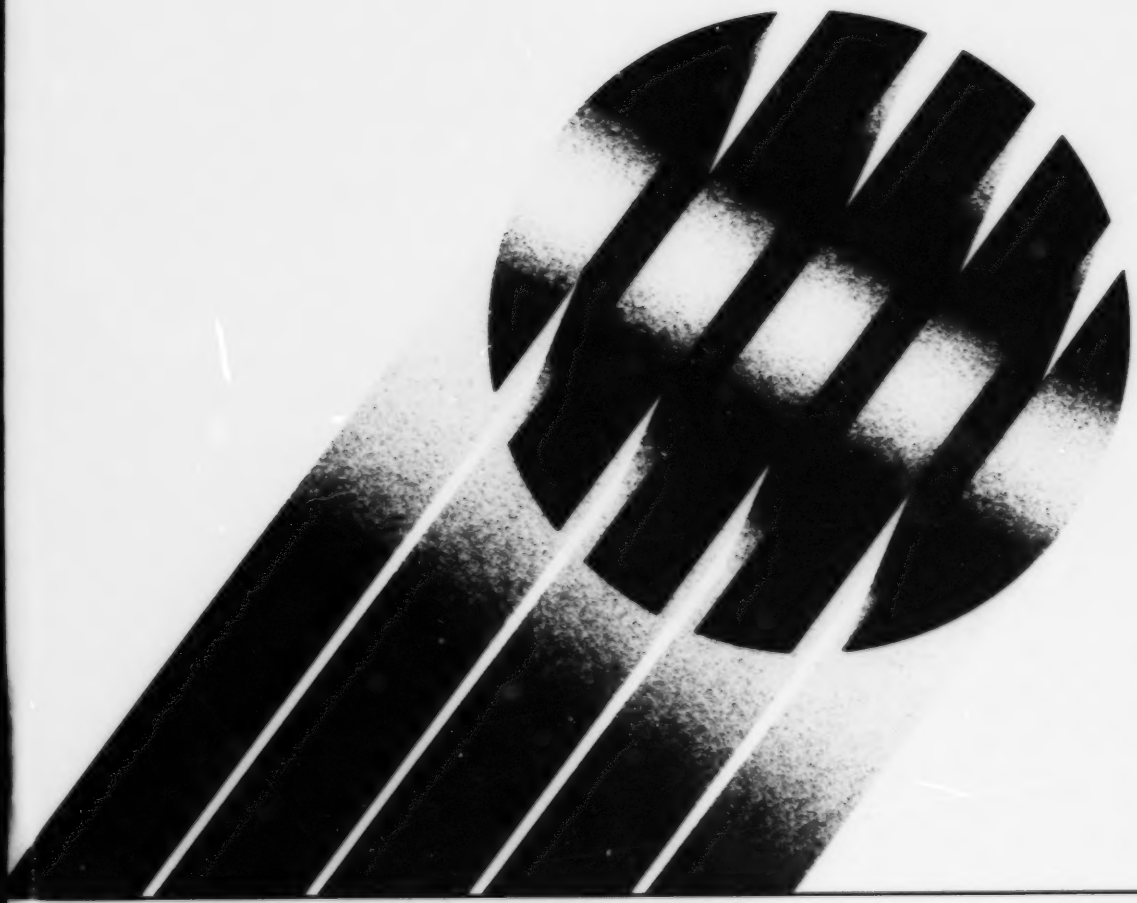
Canada Centre for Mineral and Energy Technology

Centre canadien de la technologie des minéraux et de l'énergie

## SUMMARY REPORT NO. 10: KYANITE, SILLIMANITE AND ANDALUSITE

R.K. COLLINGS AND P.R.A. ANDREWS
Mineral Processing Laboratory

MINERAL SCIENCES LABORATORIES



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**R.K. Collings and P.R.A. Andrews**
**Mineral Processing Laboratory**

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# SUMMARY REPORT NO. 10: KYANITE, SILLIMANITE AND ANDALUSITE

by

R.K. Collings* and P.R.A. Andrews**

## Abstract

The sillimanite group minerals, kyanite, sillimanite and andalusite, are identified as alumino-silicate minerals with the common chemical composition $Al_2O_3.SiO_2$, so that each possesses similar physical properties.

Kyanite is the most abundant sillimanite-group mineral and mainly occurs in Ontario, Quebec and British Columbia. Sillimanite occurs in Ontario and Manitoba, whereas andalusite occurs in Nova Scotia. There are, however, no current producers of these minerals in Canada.

The main use for the sillimanite-group minerals is in refractory applications for the production of refractory bricks or shapes. In refractory applications, the main performance criterion for these minerals, is the relative percentage of mullite formed within the material during firing. This phase gives a greater degree of resistance to creep deformation and slag attack, as well as improving the ability of the refractory to withstand high temperatures under load. Various other desirable attributes include high thermal conductivity, a low coefficient of expansion, low porosity, and an increased resistance to spalling.

Kyanite, sillimanite and andalusite have been studied extensively by CANMET and its predecessor Mines Branch between 1933 and 1987. A summary of processing data for each sample from the various deposits is presented in four appendices.

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# RAPPORT SOMMAIRE N° 10 : DISTHÈNE, SILLIMANITE ET ANDALOUSITE

**par**

**R.K. Collings* et P.R.A. Andrews****

## Résumé

Le disthène, la sillimanite et l'andalousite, minéraux du groupe de la sillimanite, sont tous des silicates d'alumine qui ont la composition chimique $Al_2O_3.SiO_2$ et qui possèdent donc des propriétés physiques semblables.

Le disthène est le plus abondant des minéraux du groupe. Il se rencontre principalement en Ontario, au Québec et en Colombie-Britannique. On trouve de la sillimanite en Ontario et au Manitoba et de l'andalousite en Nouvelle-Écosse. Actuellement, au Canada, il n'y a aucune production de ces minéraux.

Les minéraux du groupe de la sillimanite servent principalement à la fabrication de briques ou de formes réfractaires. Dans les applications réfractaires, ces minéraux ont pour critère de rendement principal le pourcentage de mullite formé dans le matériau durant sa cuisson. Cette phase augmente la résistance à la déformation par fluage et à l'attaque par le laitier, tout en améliorant la capacité du réfractaire à tolérer les fortes températures lorsqu'il est soumis à une charge. Ces produits ont d'autres qualités utiles, notamment une conductibilité thermique élevée, un faible coefficient de dilatation, une faible porosité et une résistance accrue à l'écaillage.

Entre 1933 et 1987, le disthène, la sillimanite et l'andalousite ont fait l'objet de nombreuses études à CANMET, anciennement la Direction des mines. Les données sur le traitement de chaque échantillon provenant des divers gisements sont résumées dans quatre annexes.

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# INTRODUCTION

A CANMET survey of Canadian industrial mineral producers (1) identified a number of problems specific to the industry, as well as potential opportunities for further development and expansion. Subsequent discussions with industry and government specialists identified a requirement for information in a number of areas. These areas included mineral deposits, processing, beneficiation studies and new developments, as well as information on product specifications and potential markets for Canadian industrial minerals. Related information on file at CANMET, and as available from provincial government offices and the private sector, was subsequently compiled in a series of Summary Reports on a number of industrial minerals. The information for each mineral pertains to mineral occurrences, deposits of specific interest, current activities, product uses and specifications, process technology, and summaries of past testwork on specific deposits by CANMET and others. This report, Summary Report No. 10: Kyanite, Sillimanite and Andalusite, is the tenth in the series. The previous reports are:

| | |
|---|---|
| No. 1 | Barite |
| No. 2 | Celestite |
| No. 3 | Fluorite |
| No. 4 | Silica |
| No. 5 | Mica and Vermiculite |
| No. 6 | Graphite |
| No. 7 | Gypsum and Anhydrite |
| No. 8 | Talc and Pyrophyllite |
| No. 9 | Magnesite, Brucite and Dolomite |

## Definition

Kyanite, sillimanite and andalusite, sometimes referred to as the "sillimanite-group minerals", are anhydrous aluminum silicates with the same chemical composition, $Al_2O_3.SiO_2$. Each mineral, when pure, contains 63% $Al_2O_3$ and 27% $SiO_2$ and, when heated to elevated temperatures, converts to mullite, $3Al_2O_3.2SiO_2$ and $SiO_2$.

# MINERALOGY

## Kyanite

Kyanite crystallizes in the triclinic system. The crystals are visually long, thin, blade-shaped, and usually occur embedded in schists and gneisses. They sometimes occur in radiating rosettes in a quartz matrix. The colour varies from light blue, grey-green, occasionally white and rarely black. The fracture surfaces are pearly and transparent to subtranslucent. The hardness varies from 4 to 7 on Mohs' scale depending on which cleavage face is exposed. The specific gravity is between 3.6 and 3.7 (2).

## Sillimanite

Sillimanite crystallizes in the orthorhombic system. The crystals are usually long and needle-shaped in wisp-like aggregates. The colour varies from brown and grey to green and, when fractured, the cleavage faces are vitreous and transparent to translucent. The hardness varies from 6 to 7 on Mohs' scale and the specific gravity is 3.23 (2).

## Andalusite

Andalusite also crystallizes in the orthorhombic system. The crystal form consists of a nearly square prism with basal plane and sometimes a small dome; it may also be granular or massive. The cleavage is poor, parallel to the prism. The colour varies from pearl-grey to purple-red and flesh-red; the surface is often altered to silvery-mica. The lustre is vitreous, translucent to opaque, and the fracture uneven. The hardness is 7.5 on Mohs' scale, and the specific gravity between 3.1 and 3.3 (2).

# GEOLOGY

## Origin

These sillimanite-group minerals are primarily metamorphic minerals that occur in aluminous schists, gneisses or hornfels which have undergone either regional or thermal metamorphism from their original state. It is reported that both andalusite and sillimanite may occur as igneous minerals, although the evidence is not conclusive. There are three main types of economic deposit: massive deposits in the form of boulders or lenses, disseminated material in schists or gneisses, and beach sands or alluvial deposits (3).

## Kyanite

Bennet et. al. (4) divide kyanite deposits into three distinct groups: kyanite quartzites, kyanite schists and gneisses, and massive kyanite. Kyanite quartzites are siliceous rocks containing 15 to 40% kyanite with up to 5% other minerals such as pyrite, lazulite, rutile and mica. Typical deposits are the kyanite quartzites of Georgia, and North and South Carolina in southeastern United States. Kyanite schists and gneisses may contain up to 25% kyanite and associated minerals commonly include biotite, feldspar, muscovite, garnet and hornblende. The kyanite deposits near Wanapitei and Mattawa in northeastern Ontario are typical of such occurrences. Massive kyanite may occur as nodules to large boulder-size segregations in highly metamorphosed aluminous sediments. Massive kyanite invariably contains inclusions of corundum and rutile. The kyanite deposits of India are typical of this mode of occurrence.

## Sillimanite

Sillimanite occurs as schists as well as in massive form. Sillimanite in schists typically occurs as aggregates of fine "whiskers" or needles interlaced and interlocked with quartz, mica and other minerals. Massive sillimanite occurs as nodules and boulders in metamorphic

rocks and often is associated with corundum. Such deposits occur in India, Australia and South Africa.

**Andalusite**

Andalusite is a common constituent of metamorphic rocks, although usually not as abundant as either kyanite or sillimanite. It typically is found in argillaceous and micaceous slates, and in schists and gneisses resulting from the contact metamorphism of intrusive rocks. A schist near Canso, Nova Scotia, contains 15% andalusite associated with muscovite, garnet and feldspar. A large deposit (Goat Mountain) occurs in Idaho, U.S.A., where the andalusite is closely associated with kyanite and sillimanite. Andalusite also may occur as residual, alluvial sands, having been "weathered" free from the parent rock and concentrated by the action of wind and water over a long period of time. An alluvial deposit in South Africa reportedly contains over 50% andalusite.

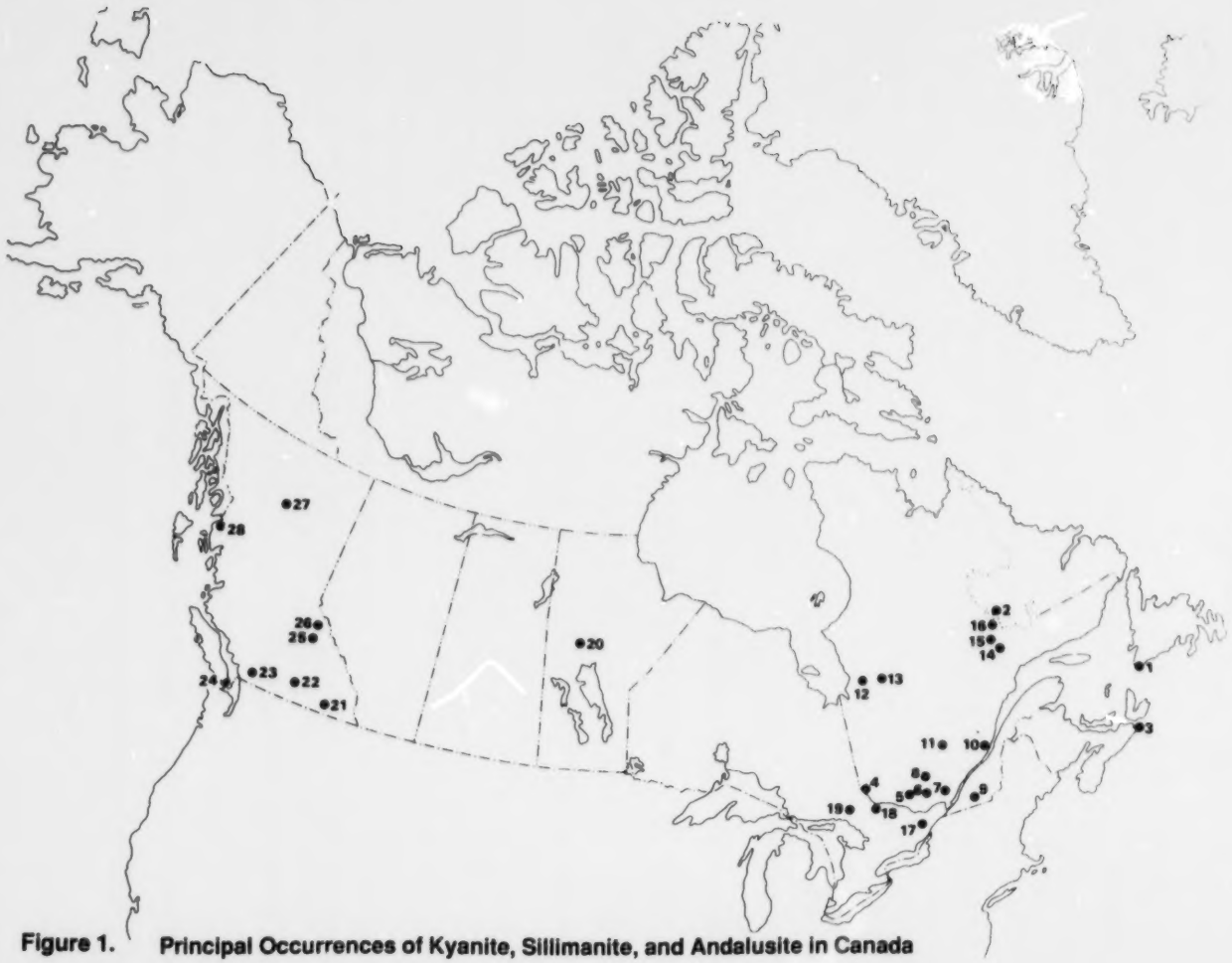
## PRINCIPAL KYANITE OCCURRENCES

Palfreyman (5) notes occurrences of kyanite in Ontario, Quebec and British Columbia. Kyanite deposits of possible economic importance in these provinces include those near Mattawa, Sudbury and Fernleigh in Ontario; near Timiskaming, Manicougan and Fermont in Quebec; and in the Big Bend area of the Columbia River in British Columbia (6-12). Kyanite has also recently been located in Newfoundland (13,14) and Manitoba (15). Principal occurrences are noted on the map in Fig. 1.

**Newfoundland**

Labrador City - Wabush

Several kyanite occurrences in the Labrador City - Wabush area of western Labrador have been studied by Meyer and Dean (13). The occurrence that appears to have the greatest



**LEGEND**

**Newfoundland**

1. Port-aux-Basques (Ky,Si)*
2. Flora Lake, Lab. (Ky)

**Nova Scotia**

3. Black Point, Dort's Cove, Doughby Point (An)

**Quebec**

4. Lac Timiskaming, Lac Beauchêne (Ky,Si)
5.. Mont Laurier (Si)
6. Mont Tremblant (Si)
7. Rawdon (Si)
8. Montauban (Si)
9. Charleroix-Tadoussac (Si)
10. Winslow (An)
11. Suzor-Letondal (Si)
12. Rivière Némiseau (Si)
13. Lac Miskittenau (Si)
14. Manicougan (Ky)
15. Lacs Gras and Felix (Ky)
16. Lac Croche (Ky)

**Ontario**

17. Fernleigh (Ky, Si)
18. Mattawa (Ky)
19. Wanipitei, Sudbury area (Ky, Si)

**Manitoba**

20. Snow Lake (Ky)

**British Columbia**

21. Southern Shuswap-Nelson (Si, Ky)
22. Shuswap Lake-Vernon-Okanagan ((Si, Ky, An)
23. Hope-Yale-Harrison Lake-Lytton (Ky, Si, An)
24. Vancouver Island (An)
25. Revelstoke- Frenchman Cap- Big Bend (Si, Ky, An)
26. Canoe River- Valemont- Mica Creek (Ky, Si)
27. Aiken Lake- Mesilinka River (Ky, Si)
28. Prince Rupert- Skeena River- Douglas Channel (Si, Ky)

* Ky- Kyanite, Si- Sillimanite, An- Andalusite

**Figure 1.** **Principal Occurrences of Kyanite, Sillimanite, and Andalusite in Canada**

potential is located 400 m west of the south end of Flora Lake. The kyanite crystals are blue, up to 5 cm in length, and occur in a garnet-mica-quartz gneiss. This prospect consists of a 30 to 50 m wide zone within a north-trending ridge that extends along the strike for a distance of 1 km. The zone contains 20% kyanite, 10 to 20% garnet, and 10 to 15% muscovite mica.

Port-aux-Basques

Kyanite and sillimanite have been identified in the Port-aux-Basques region of western Newfoundland. Brown (14) reports that staurolite crystals up to 4 cm in length, kyanite up to 10 cm, and pods of fibrolite sillimanite up to 3 cm in length, are extensively developed in a rock unit identified as Port-aux-Basques gneiss.

**Quebec**

Timiskaming

Kyanite and garnet gneisses occur in the region to the south of Timiskaming in southwestern Quebec. Cote (10) postulates that these occurrences probably are an extension of the kyanite gneisses of the Mattawa area described later in this report. The Timiskaming kyanite and garnet gneisses are described by Wilson (8) as follows:

> "In numerous localities throughout the belt of banded gneisses, especially in its southern part, bands of biotite and hornblende gneiss were observed which contained garnet. At two localities — on the north shore of Birch Lake and on the north shore of Hunters Bay, Lake Kipawa — these bands of garnet gneiss also contained kyanite. The kyanite-garnet gneiss occurring near Turtle Lake, except for the pale blue kyanite which it contains, resembles the ordinary garnet gneiss; that on Hunters Bay, Lake Kipawa, also contains muscovite".

An orebody located 16 km south of Timiskaming, under development in the late 1960s by Narco Mines Limited, was evaluated in the fall of 1969 by an extensive diamond drill program. Core sample analyses showed 10% kyanite, 5% garnet, 28% biotite, 28% muscovite and 31% quartz, indicating a low-grade, non-economic deposit.

Hébert (11) notes various occurrences of kyanite in the lac Beauchêne region, e.g., Snake Creek, where kyanite is associated with biotite and garnet; Rivière Beauchêne with 15% kyanite; and lac Hamilton with 3 to 7% kyanite.

### Manicougan

One occurrence is reported in the Manicougan region. A typical sample analyzed up to 50% kyanite, 7 to 10% biotite, 20% garnet, and contained associated feldspar and graphite (11).

### Fermont Region

Three occurrences have been identified: the lacs Gras, Félix and le Gentilhomme region, where samples analyze 0-25% kyanite with associated mica and quartz; at lac Croche, where a kyanite schist analyzes 20 to 40% kyanite with associated feldspar, biotite and quartz; and in the Gueslis-Faber-Sud area where samples analyze 20% kyanite and 15% garnet (11).

## Ontario

### Mattawa

The Mattawa area occurrence is in the northeast corner of Butler Township, district of Nipissing. The kyanite gneisses are interbanded with hornblende and biotite gneisses, and strike in a northeasterly direction with the beds dipping 30° to 45° to the northwest. A band about 300 m wide of impure quartz, containing a high percentage of pyrite and pyrrhotite, separates two roughly parallel ridges of kyanite gneiss which merge at the northeast and

southwest corners of the property, about 3 km apart. The southeast ridge of kyanite gneiss has a width of about 3600 m, and the northwest ridge a width of about 90 m.

The kyanite occurs as disseminated crystals throughout the gneiss which consists of kyanite, muscovite, biotite, quartz, feldspar and garnet. Massive interlocking aggregates of kyanite crystals are also associated with green mica and pyrrhotite, which appear to be restricted to contact zones between the kyanite gneiss, and the quartz and biotite gneisses.

It has been noted that when the grade of kyanite increases, there is an accompanying increase in the grade of quartz and decrease in the micas. Conversely, when there is a decrease in the grade of kyanite, there is an increase in the grade of muscovite and feldspar and a decrease in quartz. The great bulk of the gneiss has been estimated to analyze between 10 and 20% kyanite. Mineralogical analysis of two samples from this area are reported in Table 1.

**Table 1 - Mineral Composition of Kyanite Gneiss, Mattawa Occurrence (6)**

| Mineral | Weight % | |
|---|---|---|
| | Sample No. 1 | Sample No. 2 |
| Kyanite | 14.6 | 9.9 |
| Muscovite | 27.4 | 20.8 |
| Garnet | 14.3 | 8.6 |
| Biotite | 18.5 | 18.6 |
| Quartz and feldspars | 25.2 | 42.1 |

The disseminated kyanite crystals that occur as deep blue blades average about 10 mm in length and 5 mm in width, and usually have a random orientation in the plane of foliation. The muscovite, which occurs in flakes from 3 to 12 mm across, is contaminated with inclusions of biotite. The associated garnet is reddish brown and occurs in rounded crystals up to 10 mm in diameter. The massive variety of kyanite occurs in limited amounts in the form of lenses and stringers along the contacts between the kyanite gneiss and adjacent

quartzite and biotite gneisses. The kyanite content is >55%; the balance consists of a green mica and pyrrhotite. Although the grade of kyanite is high, the size of the individual occurrences is small and they are too few in number to be considered as economic sources of kyanite (6).

Other occurrences of kyanite in gneiss have been reported 8 km to the north and to the east, in Quebec, in the vicinity of Snake Creek and Les Erables Rapids.

Sudbury

Large deposits of kyanite gneiss occur to the east of the village of Wanapitei, 20 km east of Sudbury. The deposits lie both north and south of the main line of the Canadian Pacific railway and the Trans Canada highway.

Hewitt (7) describes the kyanite mineralization as follows:

> "The kyanite is a coarse-grained, bladed, metamorphic mineral making up 15 to 30% of the kyanite-garnet-biotite-quartz-feldspar gneiss in which it occurs. The bands of gneiss range from 1 to 120 m in width and have been traced in some cases for over 1500 m along strike. The kyanite gneissic bands dip nearly vertically and strike N.50°-80°E. The kyanite is blue, green, or grey and occurs in bladed and prismatic crystals that are from 5 to 100 mm in length, and from 2 to 12 mm in width. On weathered surfaces the kyanite stands out in prominent relief above all the other minerals, and the rock usually weathers to a distinctive reddish-brown, in contrast to the black-weathering garnet amphibolites with which it is associated. The minerals of the gneiss are strongly aligned; the kyanite in this area shows pronounced lineation in the plane of foliation".

As in the Mattawa area, the principal non-kyanite mineral constituents of the gneiss are garnet, biotite, muscovite, quartz and feldspar; some sillimanite is also present. Biotite is the dominant mica, except for local concentrations of muscovite. Structural faulting, thickening, thinning, and drag folding of beds have resulted in wide variations in the mineral compositions of the rocks in the area. Some bands consist essentially of biotite and kyanite,

with minor feldspar; others of kyanite, feldspar, quartz and garnet, with subordinate biotite. The grade of kyanite likewise exhibits considerable variation. Sampling to date, however, has indicated extensive bodies of gneiss up to 1200 m in width containing about 25% kyanite.

Pearson (9) notes that kyanite in this area occurs in kyanite gneiss, kyanite-sillimanite gneiss, kyanite pegmatites, and kyanite-bearing quartz veins, but states that the kyanite gneiss contains the only kyanite that is of possible economic importance. Thin sections made from samples of kyanite gneiss showed 3 to 30% kyanite, 17 to 52% quartz, 8 to 37% plagioclase, 6 to 29% biotite, 1 to 25% garnet, 1 to 21% muscovite and 0 to 7% microcline; apatite, zircon, magnetite and graphite occurred as accessory minerals. Sillimanite was present as a minor constituent in two thin sections.

### Fernleigh

A band up to 100 m wide of fine-grained mica schist containing kyanite runs northeasterly across Clarendon Township in southeastern Ontario, about 80 km north and slightly west of Kingston. Two occurrences in this band, 1.5 and 3.0 km east of the village of Fernleigh, have received attention. The kyanite occurs in crystals up to 12 mm in length disseminated in a fine-grained mica schist, and as "logs" up to 20 cm long irregularly scattered throughout the schist. Garnet is also present, along with minor amounts of staurolite and sillimanite. Analyses of the richer portions of the schist indicate a kyanite content of 12 to 15% over a 9 m width (6).

## Manitoba

### Snow Lake Area

Several occurrences have been reported in the Snow Lake area. Minor occurrences are also known in the Lynn Lake area, on Karsakuwigamak Lake, on Gorman Lake, on Knee Lake,

east of Knife Lake on Cat Eye Bay, at Oxford Lake (alteration zone), and along the eastern shore of Lake Winnipeg, east of Black Island.

The Anderson zinc-copper mine in the Snow Lake area contains several lenses of kyanite-rich sericite schist as well as disseminated kyanite crystals in chloritic schist. Other copper-zinc mineral occurrences contain aggregates of chlorite-garnet-staurolite-kyanite with some gahnite and biotite. Little is known of the extent and concentration of this potentially valuable by-product of the zinc-copper mines (15).

**British Columbia**

Pell (10) notes numerous occurrences of sillimanite-group minerals in three linear belts or formations: the Omineca Crystalline Belt extending in a southeasterly direction from the north-centre to the U.S. border in the southeast; the Coast Mountain Belt extending in a southeastern direction from north to south along the western mainland coast; and the Insular Belt that lies to the west of the Coast Mountain Belt and includes Vancouver Island. These occurrences are grouped in areas in each of the three belts in Table 2.

**Table 2 - Sillimanite-Group Minerals Occurrences in British Columbia** (12)

| Belt | Area* | Mineral** |
|---|---|---|
| Omineca | Southern Shuswap-Nelson (21) | Si,Ky |
| | Shuswap Lake-Vernon-Okanagan (22) | Si,Ky,An |
| | Revelstoke-Frenchman Cap-Big Bend (25) | Si,Ky,An |
| | Canoe River-Valemount-Mica Creek (26) | Ky,Si |
| | Aiken Lake-Mesilinka River (27) | Ky,Si |
| Coast Mountain | Hope-Yale-Harrison Lake-Lytton (23) | Ky,Si,An |
| | Prince Rupert-Skeena River-Douglas Channel (28) | Si,Ky |
| Insular | Vancouver Island (24) | An |

*Numbers in brackets are map locations, Fig. 1.

**Si-sillimanite; Ky-kyanite; An-andalusite

Big Bend

Haw (6) reported that gneissic kyanite samples from the Big Bend area of the Columbia River, sent to the Mines Branch in Ottawa in 1931, consisted mainly of coarsely crystalline kyanite aggregates associated with pegmatitic material. These samples were reported to be from boulders between Death and Priest Rapids. Later samples from the vicinity of Boat Encampment were of the disseminated gneissic variety. A mineral analysis of the mineral composition of this gneiss (Table 3) was very similar to that of the kyanite gneiss occurring in Ontario. The rock samples were highly foliated with finely crystalline biotite and muscovite as the dominant constituents. The kyanite blades, up to 12 mm in length, were bluish-grey in colour and oriented haphazardly in the plane of foliation. Dark red, 6 mm diameter, garnet crystals were disseminated throughout the rock.

**Table 3 - Mineral Composition of Kyanite Gneiss from the Big Bend Area of British Columbia** (6)

| Mineral | Weight % |
|---|---|
| Kyanite | 10.7 |
| Muscovite | 20.0 |
| Garnet | 14.1 |
| Biotite | 27.0 |
| Quartz and feldspar | 23.8 |
| Staurolite | 4.3 |

Strata within these areas locally contain in excess of 10 to 15% sillimanite-group minerals. The economic viability, however, has not been determined.

## PRINCIPAL SILLIMANITE OCCURRENCES

Palfreyman (5) notes occurrences of sillimanite in several provinces including British Columbia, Manitoba, Ontario, Quebec and Nova Scotia, as well as on Baffin Island, Northwest Territories.

### Quebec

Hébert (11) identifies more than twelve regions in which about twenty occurrences of sillimanite are recorded. These are noted on the map in Figure 1, and are listed in Table 4, with locations and brief descriptions.

### Ontario

#### Otter Creek

Black (16) describes an occurrence of sillimanite at Otter Creek, 10 km east of Tweed, in southeastern Ontario. The sillimanite occurs in a coarse-grained peltic schist, the northern limit of which is recorded as being 3 km long by 400 m wide, and the southern limit 3 km long by 100 m wide. The sillimanite occurs as fibrous clots associated with garnet, muscovite and biotite, and is reported to make up 20% of the total volume of the schist formation. An investigation of a representative sample from this occurrence (17) provided a mineralogical analysis as follows: 21.9% sillimanite, 52.0% mica, 18.6% quartz, 5.4% garnet and 2.1% magnetite.

#### Clarendon

Black and Rencz (18) describe a second occurrence of sillimanite at Clarendon, located 4 km north of the village of Ardoch and 60 to 65 km north-northeast of the Otter Creek

## Table 4 - Sillimanite Occurrences in Quebec (11)

| Region | Occurrence |
|---|---|
| Beauchêne (Timiskaming) | Lac Smith:<br>- rock containing 15% sillimanite which outcrops over 200 m<br>Lac Coney-Nord:<br>- gneiss containing 15 to 20% sillimanite |
| Mont Laurier | Lac Boyd:<br>- small occurrence of graphite with associated sillimanite |
| Mont Tremblant | Lac Tremblant:<br>- garnet gneiss with abundant sillimanite and associated with calcite, quartz and mica |
| Suzor-Letondal (134 km NW of La Tuque) | Lac Alex:<br>- visible crystals of sillimanite in paragneiss |
| Rawdon (67 km NNE of Montreal) | Saint Jean-de-Matha:<br>- sillimanite-garnet gneiss with about 20% sillimanite<br>Boscoville:<br>- sillimanite-garnet gneiss with 22% sillimanite, 15% garnet<br>Rivière Noire:<br>- abundant sillimanite in garnetiferous gneiss |
| Montauban (120 km west of Quebec) | Notre Dame-des-Anges:<br>- sillimanite in biotite gneiss<br>Notre Dame-de-Montauban:<br>- sillimanite in an 8 m wide gneissic band in quartzite |
| Charlevoix-Tadoussac (150 km NE of Quebec) | La Galette:<br>- one sample from this occurrence analyzed 50% sillimanite with associated rutile, zircon, and alteration products<br>Lac Boucher:<br>- 5% sillimanite with cordierite and quartz |
| Rivière Némiscau (225 km NW of Chibougamau) | Lac Senay:<br>- sample from this occurrence analyzed 11% sillimanite, 52% quartz, 27% altered silicates of aluminum, 5% muscovite and 3% garnet<br>Lac Chlorite:<br>- sample analyzed 46% sillimanite, 50% quartz, with minor feldspar, biotite and tourmaline<br>Lac Rond:<br>- sample analyzed 25% sillimanite, 40% quartz, 17% cordierite, 10% biotite and 4% garnet<br>Lac Lemare:<br>- paragneiss nodules rich in sillimanite, andalusite and cordierite |
| Lac Miskittenau (40 km west of Lac Mistassini) | Rivière Cuttings:<br>- local concentrations of sillimanite and cordierite |

occurrence. This sillimanite occurrence is also contained in a peltic schist which has a length of 2.5 km and average width of 250 m. The schist contains three main sub units as follows:

1. a zone with 15 to 35% sillimanite in the form of clots with associated garnet, biotite and muscovite.
2. a zone with 0 to 15% sillimanite associated with major muscovite and biotite.
3. a zone containing less than 15% sillimanite and 30% large plagioclase prophyroblasts measuring 3 to 4 cm in diameter, associated with muscovite, biotite and quartz.

A mineralogical analysis of a representative sample from this occurrence was as follows: 24.6% sillimanite, 46.0% mica, 22.6% quartz, 5.6% garnet and 1.6% magnetite (17).

Wanapitei Area

Pearson (9) describes sillimanite occurrences in the Wanapitei area of Ontario, noting that sillimanite-bearing lenses from a fraction of a cm to more than 2.5 cm in width, and from 0.3 to 3 m long, occur along shears in the kyanite gneiss formations in this area. The sillimanite is of the fibrolite variety with a silky lustre, and pale-brown to greyish-white colour. Associated minerals include garnet, biotite, muscovite, quartz and feldspar.

## PRINCIPAL ANDALUSITE OCCURRENCES

Palfreyman (5) notes occurrences of andalusite in several provinces including British Columbia, Ontario, Quebec, New Brunswick, Nova Scotia and Newfoundland, as well as in the Yukon and Northwest Territories; however, none of these is extensive.

**Nova Scotia**

The most important occurrences are those at Black Point, Dort's Cove and Doughby Point in the Canso area.

Black Point

The Black Point occurrence is about 13 km west of Canso on the south side of Chedabucto Bay. The andalusite at Black Point occurs as elongated, prismatic crystals in black, slatey schist. This schist is exposed continuously over a length of 50 m, and at scattered outcrops over a total length of 450 m or more. The schist is 150 m in width at the eastern extremity and narrows to 60 m or less toward the west. The andalusite crystals reportedly comprise 20 to 25% of the total material in the formation (19). This deposit was investigated in the late 1950s. A petrographic examination of typical samples indicated 5 to 10% andalusite, 50 to 60% mica, 5 to 20% carbon as graphite, and minor quartz and chlorite. Beneficiation trials resulted in a concentrate grading 85.8% andalusite with a recovery of 45.2% of the contained andalusite (20).

Dort's Cove

The Dort's Cove deposit was explored by several companies during the period 1957 to 1964. Diamond drilling results indicated 30 Mt of ore grading 25% $Al_2O_3$ (21). Pilot plant studies of a 65-barrel shipment of slate from this area were undertaken by Mines Branch (CANMET) in the late 1950s (22).

Doughby Point

The Doughby Point occurrence is 15 km southwest of Canso on the north end of Whitehead Harbour at the entrance to the northwest arm. The andalusite is contained in a schist formation which has a width of 450 m at the eastern extremity, and an andalusite content of

25 to 30%. The width narrows over a length of 2000 m to 300 m at the western extremity, where the andalusite content drops to 5% (23). A petrographic examination of a typical sample analyzed: 32% andalusite, 49% muscovite-biotite-quartz, 11% garnet, 4% magnetite, and 3% quartz. The andalusite crystals were observed to contain numerous inclusions of carbonaceous material, quartz and garnet, so that only about 50 to 75% of each crystal was, in fact, andalusite (24).

**Quebec**

Hébert (11) reports six or more areas in which andalusite occurrences have been noted: Mont Mégantic, 195 km east of Montreal; Winslow, 120 km south of Quebec; les Monts Sainte-Cécile et Saint-Sébastien, 125 km south-southeast of Quebec; lac aux Araignées, 15 km south of Mégantic; in the Bosquet mine, 42 km east of Rouyn-Noranda; and in the Grand-Détour-lacs Village region, 275 km north-northwest of Chibougamau. The Winslow occurrence is reported to contain up to 50% andalusite.

**British Columbia**

Andalusite occurs, as previously noted, with kyanite and sillimanite in a number of areas in British Columbia (Table 2).

## MINING

Mining of the sillimanite-group minerals is by open-pit methods because in-place gneissic or schistose deposits are normally near the surface. Typical of kyanite quarrying operations is a mine at Svenska Kyanite AB, Sweden, where the surface pit is worked in 10 m benches by vertical blasting. The broken ore is extracted using a mechanical digger and transported to a mobile crushing plant, where it is reduced to 20 mm size (25).

The mining of andalusite in South Africa is similar. At Rand London, the deposit is mined by open-cast methods, with drilling and blasting of 12 m benches with wagon drills. Overburden, which consists of rubble and soil, is removed on an intermittent basis. Loading of the broken ore is by front-end loaders into 17 t trucks, which convey it to the primary crushing section (26).

## PROCESSING

The processing of the sillimanite-group minerals is basically the same for each because of the similarity of the associated gangue minerals. Following primary comminution at the pit site, secondary comminution by cone or rolls crushers reduces the ore to liberation size. Beneficiation is then achieved by a variety of wet and dry processing methods. Mineral contaminants such as magnetite, biotite, and garnet may be removed by high-intensity, dry or wet magnetic separation; muscovite, quartz, and feldspar are responsive to gravity methods of separation including dry or wet jigging and tabling. Flotation is used to either float gangue minerals for discarding, or to directly float (and thus beneficiate) the sillimanite-group minerals. Alluvial or beach sand deposits normally are sized and treated by one or more of the various beneficiation processes to recover kyanite, sillimanite and andalusite. Andalusite, being heavier than kyanite, may be treated by heavy media separation to recover coarse sizes, and by flotation to recover the fine sizes.

The included flow diagrams are illustrative of beneficiation procedures for the recovery of kyanite. The flow diagram depicted in Figure 2 was developed by Haw (5) for the processing of ore samples from the Mattawa kyanite deposit; that shown in Figure 3 was used by Narco (9) in processing kyanite ore from the Timiskaming area deposit.

A flow diagram of a typical andalusite operation is depicted in Figure 4 (27).

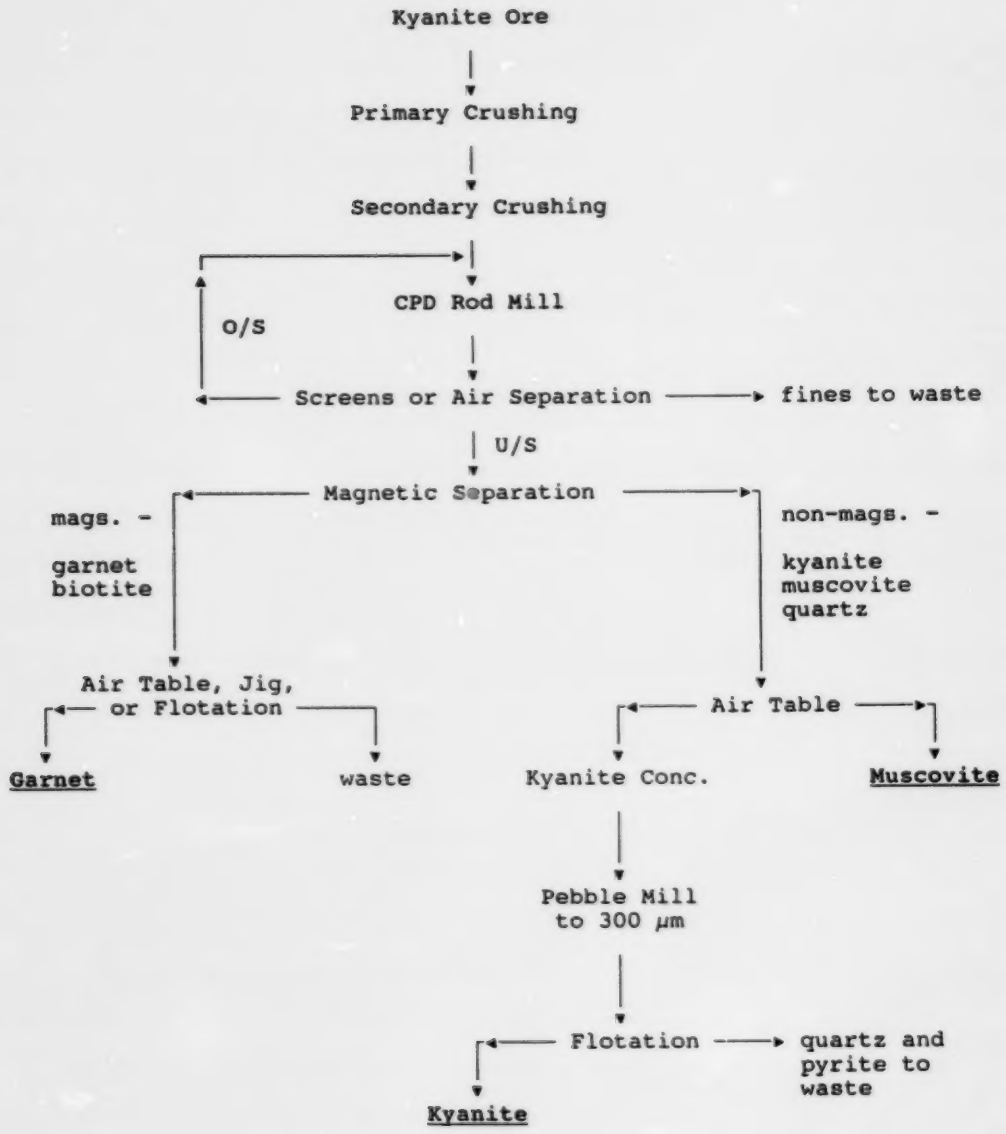



Fig. 2 - Flow Diagram for the Recovery of Kyanite, Muscovite and Garnet Products from the Mattawa Area Kyanite Deposit (6)

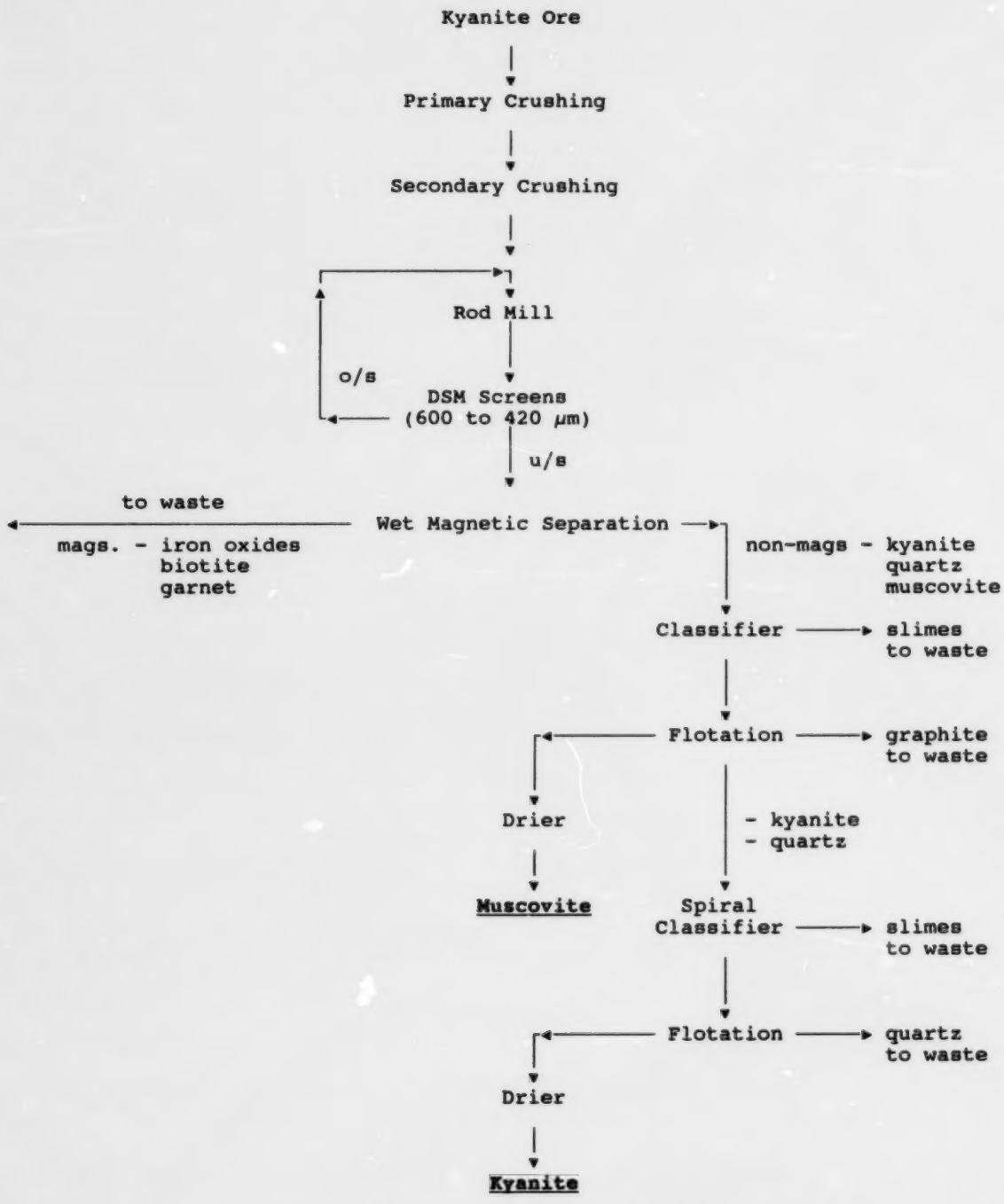



Fig. 3 - Flow Diagram for Recovery of Kyanite and Muscovite Products from the Timiskaming, Quebec, Kyanite Deposit; NARCO Mines Limited (10).

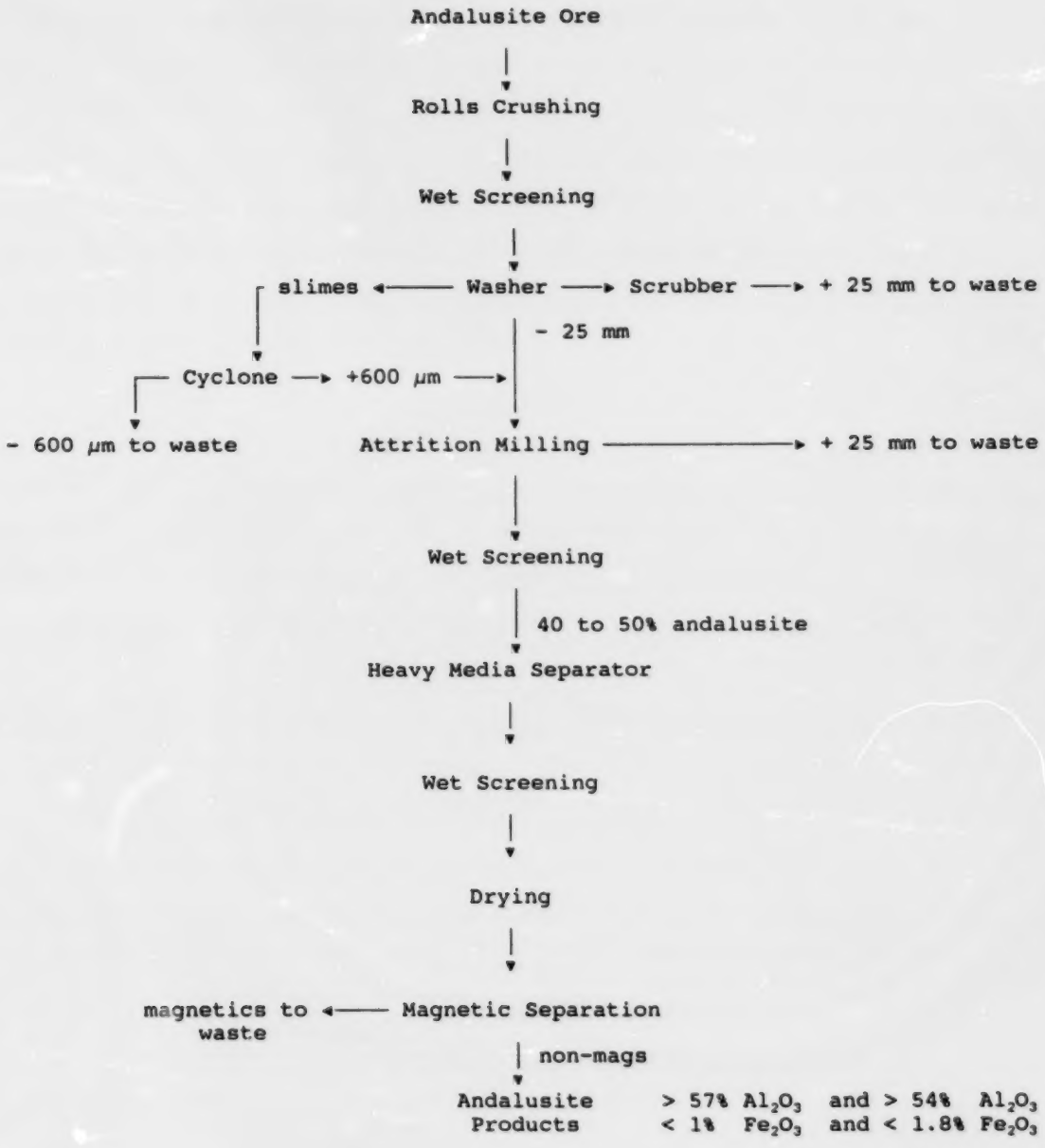



Fig. 4 - Flow Diagram for the Beneficiation of South African Andalusite (27).

## REFRACTORY PROPERTIES OF SILLIMANITE MINERALS (28)

In refractory applications, the main performance criterion for alumina materials is the relative percentage of mullite formed within the material during firing. All three sillimanite minerals should therefore be regarded as mullite-producing. At a critical temperature the sillimanite structure breaks down to form the stable high-temperature mullite phase with excess silica.

$$\underset{(sillimanite)}{3Al_2O_3.SiO_2} \rightarrow \underset{(mullite)}{3Al_2O_3.2SiO_2} + \underset{(quartz)}{SiO_2}$$

The decomposition temperature, however, varies for the three sillimanite-group minerals (Table 5), and the process is further complicated by the rate of temperature increase, grain size, and impurities present. The period of heat treatment is also a factor to be considered because mullitization begins on the surface of the grains and proceeds inwards. The chemistry of the raw material is also very important. An alumina content of 71.8%, close to the theoretical content of mullite, is required for optimum mullite formation. This factor is the major consideration for the use of sillimanite minerals as high-alumina, mullite-forming refractories.

**Table 5 - Mullite Formation Characteristics of the Sillimanite-Group Minerals**

| Mineral | Specific gravity | Temperature of mullitization | Volume change on conversion |
|---|---|---|---|
| Andalusite | 3.20 | 1380°C | +5% |
| Sillimanite | 3.23 | 1550°C | +7% |
| Kyanite | 3.65 | 1350°C | +18% |
| Mullite | 3.05 | - | - |

The temperature of transformation and the various associated physical phenomena differ appreciably among the three minerals and confer distinct physical properties on the manufactured products. Kyanite is the most easily mullitized and transforms at temperatures between 1350° and 1380°C. This relatively low temperature is advantageous with regard to energy costs as kyanite is normally calcined before use because of its inherent expansion characteristics. Raw kyanite expands by 18% under firing, although this is partly dependent upon the grain size and the ambient temperature. This expansion can be controlled and used to advantage in offsetting the firing shrinkage of other raw materials such as clays. However, if the volume increase is undesirable, the kyanite must be calcined before use to ensure dimensional stability.

Andalusite changes to mullite at a slightly higher temperature (between 1380° and 1400°C), however, because the accompanying volume increase is minimal, it can be fired in situ without prior calcination. Sillimanite is only changed conclusively at a much higher temperature (about 1550°C), but the associated volume change is also insignificant.

The refractory properties of the sillimanite-group minerals are determined by the relative percentage of mullite. This mullite phase gives a greater degree of resistance to creep deformation and slag attack, as well as improving the ability to withstand high temperatures under load. Various other desirable properties include high thermal conductivity, a low coefficient of expansion, low porosity, and an increased resistance to spalling.

## USES AND SPECIFICATIONS

The sillimanite-group minerals contain a maximum of about 63% $Al_2O_3$. Impurities are generally detrimental to the refractory properties of these minerals; the most harmful, such as iron, titanium and the alkalies, should be kept to a minimum. The iron oxide content should be $<1.0\%$ $Fe_2O_3$, the titania content $<2.0\%$ $TiO_2$, and the total alkali (including CaO, MgO, etc.) $<0.3\%$. Typical chemical and physical properties of various sillimanite-group materials are reported in Table 6.

**Table 6 - Typical Chemical Analyses for the Sillimanite-Group Minerals** (3,29)

| Oxide constituent | Analysis, % | | | | |
|---|---|---|---|---|---|
| | Kyanite U.S.A. | Andalusite S. Africa | Pure $Al_2O_3.SiO_2$ | Pure Mullite | Fused Mullite |
| $Al_2O_3$ | 56.6 | 59.5 | 62.9 | 71.8 | 76.2 |
| $SiO_2$ | 40.0 | 39.2 | 37.1 | 28.2 | 23.0 |
| $Fe_2O_3$ | 1.0 | 0.9 | - | - | 0.1 |
| $TiO_2$ | 1.0 | 0.14 | - | - | - |
| CaO | 0.5 | 0.06 | - | - | 0.2 |
| MgO | 0.5 | 0.12 | - | - | 0.1 |
| $K_2O$ | tr | 0.20 | - | - | 0.4 |
| $Na_2O$ | tr | 0.10 | - | - | - |
| LOI | - | 0.50 | - | - | - |
| Particle size | | | | | |
| +6 mm* | | 27.0 | | | |
| -6 + 3.3 mm | | 72.3 | | | |
| -3.3 + 1.7 mm | | 0.7 | | | |
| -1.7 mm | | - | | | |

*From 420 to 44 μm in closely sized fractions

The production of refractory bricks or shapes from the sillimanite minerals is not difficult, but to achieve the required degree of strength under load requires a fairly high percentage, about 60%, of coarse grain-size material. The coarse or boulder grades of sillimanite minerals are in particular demand for high-duty bricks because they yield a denser, tougher, and coarser-base material. Fine-grained material, which can be produced to the same chemical quality, is therefore only useful when it can be blended with massive sillimanite minerals to give the correct balance of coarse and fine particles necessary for a dense brick. Fine-grained material mixed with clay may be used for kiln furniture, insulating bricks and fire bricks. The finest material is used in sanitary ware, wall tiles and in precision casting moulds.

A summary of the main areas where the sillimanite-group minerals are used is reported in Table 7.

**Table 7 - Refractory Shapes for the Steel and Other Industries** (30)

**Refractory shapes for the steel industry**

Hot blast stoves
- Checker bricks (upper zone)
- Dome
- Combustion shaft

Blast furnaces
- Lining of stack and bosh area
- Bustle pipe
- Tilting troughs
- Swivelling troughs
- Iron and slag runners

Ladles
- Large-capacity ladles (slag line)
- Torpedo ladles (bottom and slag line)
- Steelworks ladles
- Continuous casting tundishes

Other applications
- Soaking pit covers
- Nozzles for blowing argon

**Refractory shapes for various industries**

- Burner bodies
- Combustion chambers
- Cement kilns (zones before and after the burning zone, which itself is lined with basic bricks)
- Copper roasting furnaces
- Linings for certain parts of glass furnaces
- Kiln furniture for firing ceramic products

Mullite refractories are utilized principally in the form of bricks and shapes in the metallurgical and glass industries. They also find use in refractory cements, mortars, plastics and ramming mixtures. It has been estimated that 50% of all mullite refractories are utilized in metallurgical industries, 40% in the glass industry, and 10% in other applications.

In the metallurgical industries, mullite refractories are used in linings for electric furnaces for melting high-copper bronzes, brasses and copper-nickel alloys, and in zinc smelting and gold refining furnaces. Some ferrous smelting, at 1650°C or higher, also requires mullite or similar refractories. In small direct-arc furnaces, or any furnace in which intermittent operation is practised, mullite refractories are particularly adaptable because of their resistance to thermal shock. They also find important use in electric furnace door jambs, arches, and burner blocks.

In the glass industry, these refractories are used mainly in the superstructure of glass batch tanks and in plungers and feeders. Mullite refractories are also used in kiln furniture and for lining laboratory test kilns. Other uses include electrical porcelains and pyrometer tubes, and as a source of alumina in glass batches (4,6).

**Kyanite**

Kyanite is the most abundant of the sillimanite-group minerals and therefore is the most widely used. Kyanite is usually not available in grain sizes as large as that of andalusite, but it has an advantage with regard to the nature of iron contamination. The concentration of iron contamination may be the same as for andalusite, but whereas iron contamination in andalusite is more localised, iron in kyanite is in a more discrete, disseminated chemical form.

The refractory industry accounts for about 95% of all kyanite production; the remaining 5% is used in various applications such as the manufacture of welding rod fluxes, insulation and brake shoes. Kyanite is frequently added to ceramics and fireclay refractories to counteract the shrinkage on firing; its expansion properties are utilized in ramming mixes.

**Sillimanite**

Sillimanite is the least commonly used mineral of the group because economic reserves are less common. Sillimanite may be used in applications similar to those for kyanite and andalusite, and also in the manufacture of grinding pebbles for contamination-free grinding (especially iron contamination) of nearly white mineral fillers and additives.

**Andalusite**

Andalusite has advantages over other alumina-bearing refractories in the manufacture of bricks, particularly bricks having complex shapes. There is no large volume change, and the changes during firing are slight, thus ensuring better dimensional tolerance and warpage characteristics. Andalusite is also the only mineral that can be used in its natural grain size as an aggregate in brick manufacture (29).

Andalusite's inherent properties of high hot strength, low porosity, good spalling resistance and high volume stability, make it comparable with 85 to 90% alumina bricks. The performance, under transportation conditions, is superior because of the sealing action of the softened surface zone.

Andalusite is mostly used in the manufacture of high-alumina refractories; a small proportion is used for ceramic purposes. Andalusite refractories are favoured under abrasive conditions, where high loads and high temperatures are encountered. In hot-blast stoves, they are used as checker bricks in the upper zone, in the dome, and in the combustion shaft. In blast furnaces, andalusite refractories are used in the lining of the stack and bosh areas, in tilting and swivelling troughs, as linings for iron and slag runners, and as tap-hole muds. Andalusite also finds application in general purpose ladles.

Other applications include use as soaking-pot covers, nozzles for the blowing of argon gas, refractory shapes such as burner bodies and combustion chambers in cement kilns, linings for

glass furnaces, kiln furniture for the firing of ceramic products, and in copper-roasting furnaces. Andalusite is also used in unshaped refractory applications such as castable or gunning mixes, ramming mixes, foundry sand, roofs of reheat furnaces, and heat-treatment furnaces. Special-purpose products include sanitaryware and whiteware, and high-temperature applications such as spark-plug bodies, insulators and pyrometer tubes (29).

## CURRENT INTEREST AND DEVELOPMENTS

Canadian occurrences of kyanite, sillimanite and andalusite are generally considered to be non-economic resources of refractory raw material because of low-grade and intimate association with mineral contaminants such as mica, pyrite, hornblende, quartz and feldspar. Notable exceptions include the Wanapitei and Mattawa kyanite deposits in Ontario and, possibly, the Timiskaming kyanite deposit in Quebec and the Canso-area andalusite deposit in Nova Scotia.

### Quebec

Narco Mines Limited, a subsidiary of North American Refractories Limited, was formed in 1967 to bring a kyanite property located 16 km south of the village of Timiskaming, Quebec, into production. Recovery of kyanite, unfortunately, was substantially below expectations. Follow-up drilling did not substantiate the original grades, the average kyanite being only 8%; the associated minerals analyzing 30% quartz, 28% muscovite, 28% biotite and 8% garnet. The possibility of marketing mica and garnet co-products was investigated, however, this proved to be non-economic and the operation was closed (10).

Mazarin Inc. is investigating a quartz-mica-kyanite schist at lac Croche, 30 to 40 km south-southeast of Fermont, Quebec, for possible development. The schist is reported to be 300 m wide and 600 m in length along the strike. The deposit was discovered in 1986 by a joint prospecting venture of La Société d'Exploration Minière Mazarin Incorporated, and Les Fonds d'Exploration Minière du Nouveau Québec. Samples from the deposit analyzed

50.7% $Al_2O_3$, 36% $SiO_2$, 6.24% total iron, 1% MgO, 0.96% $TiO_2$ and 0.71% CaO. A preliminary tonnage estimate for the deposit to a depth of 300 m was 4.5 Mt (31).

**Ontario**

Northern Kyanite Mines Limited was formed in the early 1950s to explore and develop the Wanapitei area kyanite. The company at that time held 43 claims in Dryden township, and assessment work included trenching, bulk sampling and diamond drilling. Results showed the presence of at least one major deposit, "C", containing 1.8 Mt of ore grading 18.27% kyanite over a length of 610 m with an average width of 43 m, and a depth of 31 m. The ultimate depth of the deposit was not determined, however, several holes drilled to 55 m were still in ore. Work on bulk samples by Lakefield Research Limited produced about 1.8 t of concentrate grading 90 to 92% kyanite by a combination of jigging, flotation and magnetic separation (9). Dry and wet processing flowsheets developed by CANMET (Mines Branch) produced similar high-grade concentrates and a co-product garnet. CANMET was also successful in developing a process for stabilizing the kyanite, and for producing a mullite aggregate with superior refractory properties. Despite detailed market studies carried out at that time, the deposits did not achieve commercial production.

An intensive study of the Mattawa area kyanite was undertaken by CANMET (Mines Branch) in the early 1950s (6). This occurrence is in the northeast corner of Butler township, 32 km north of Mattawa. Representative samples were processed by both dry and wet methods. The results of this study are summarized as follows:

> "The overall recovery of kyanite in both dry and flotation stages of concentration, utilizing the air-table, is calculated to be 72%, with the production of a concentrate containing in excess of 90% kyanite. By eliminating the air table and floating the magnetic tailing directly, the recovery was increased to 80%. Muscovite recovery by dry methods of concentration is about 60%. The chief losses of muscovite were in magnetic separation".

Kyanite Corporation of Canada, Limited undertook extensive exploration of a large kyanite-muscovite gneissic formation located at the north-east end of Crocan Lake, 35 km northeast of Mattawa in the mid 1950s. The main deposit has a width of 360 m and a probable thickness of 180 m. The kyanite content varies from 12 to 20%. A second occurrence is 90 m wide and an estimated 45 m in thickness. Work on samples from this deposit by CANMET (Mines Branch) was reported earlier in this report (6). Narrow lenses of massive, kyanite-rich material occur along the contact zones. These may contain 80 to 90% kyanite and are of considerable interest as high-grade occurrences of kyanite (32).

## PRODUCTION AND TRADE

There is no production of kyanite, sillimanite or andalusite in Canada at present. Imports for use in refractory applications are relatively minor and are mostly from the United States. Statistical data, by province, for 1988 and 1989 are reported in Table 8.

**Table 8 - Imports of Kyanite, Sillimanite and Andalusite***

| Province | 1988 | | 1989 | |
|---|---|---|---|---|
| | kg | $ | kg | $ |
| Quebec | 1,092,065 | 250,000 | 1,209,869** | 291,000 |
| Ontario | 5,029,610 | 935,000 | 4,879,627 | 849,000 |
| Alberta | - | - | 20,000 | 5,000 |
| British Columbia | 100,111 | 13,000 | 54,480 | 7,000 |
| Total imports | 6,221,793 | 1,199,000 | 6,163,977 | 1,153,000 |

*Statistics Canada, International Trade Division

**Includes 528,000 kg valued at $106,000 from South Africa

## PRICES (33)

U.S. kyanite is sold in raw and calcined forms. Raw kyanite prices are between U.S. $70 and $137/t, whereas calcined kyanite is between U.S. $123 and $172/t. The price for bulk

shipments of 59 to 62% $Al_2O_3$, minus 420 plus 44 $\mu$m, raw/calcined, in 16.5 t lots is between U.S. $144 and $248.

Sillimanite from South Africa, grading 70% $Al_2O_3$, sells for $300/t. Andalusite from South Africa is sold in two grades: 60% $Al_2O_3$ is about U.S. $200/t, and 57% $Al_2O_3$ about U.S. $150/t.

## CANMET STUDIES

### Background

Eighteen CANMET kyanite beneficiation studies (34-51), and four studies (52-55) by other organizations were reviewed. Two CANMET sillimanite beneficiation studies (56,57), and three CANMET andalusite studies (58-60) were also reviewed. Summaries of CANMET kyanite studies are presented in Appendix 1, and of the four studies by other organizations in Appendix 2. Summaries of CANMET sillimanite studies are presented in Appendix 3, and summaries of the CANMET andalusite studies in Appendix 4.

The summary of each study includes, if known, the original sample weight, head analysis, mineralogy, beneficiation methods, beneficiation product sizes, concentrate grades and recoveries, as well as remarks or observations of particular interest. The original sample weight is indicative of the scale of investigation, whether bench, laboratory, semi-pilot plant or pilot plant. The head analyses provide data concerning the mineral content and whether the sample originates from a high or low-grade deposit. Mineralogical information not only identifies major and minor minerals, but also provides data regarding association between minerals and host rocks. The liberation size in many cases is either not known or not stated; the beneficiation product size is quoted since, by inference, product size under optimum test conditions usually equates to liberation size. Beneficiation methods are important as a guide for future studies of ores with similar mineral assemblages, and concentrate grade and recovery figures provide an indication of how efficient the beneficiation methods were in

Kyanite Corporation of Canada, Limited undertook extensive exploration of a large kyanite-muscovite gneissic formation located at the north-east end of Crocan Lake, 35 km northeast of Mattawa in the mid 1950s. The main deposit has a width of 360 m and a probable thickness of 180 m. The kyanite content varies from 12 to 20%. A second occurrence is 90 m wide and an estimated 45 m in thickness. Work on samples from this deposit by CANMET (Mines Branch) was reported earlier in this report (6). Narrow lenses of massive, kyanite-rich material occur along the contact zones. These may contain 80 to 90% kyanite and are of considerable interest as high-grade occurrences of kyanite (32).

## PRODUCTION AND TRADE

There is no production of kyanite, sillimanite or andalusite in Canada at present. Imports for use in refractory applications are relatively minor and are mostly from the United States. Statistical data, by province, for 1988 and 1989 are reported in Table 8.

**Table 8 - Imports of Kyanite, Sillimanite and Andalusite***

| Province | 1988 | | 1989 | |
|---|---|---|---|---|
| | kg | $ | kg | $ |
| Quebec | 1,092,065 | 250,000 | 1,209,869** | 291,000 |
| Ontario | 5,029,610 | 935,000 | 4,879,627 | 849,000 |
| Alberta | - | - | 20,000 | 5,000 |
| British Columbia | 100,111 | 13,000 | 54,480 | 7,000 |
| Total imports | 6,221,793 | 1,199,000 | 6,163,977 | 1,153,000 |

*Statistics Canada, International Trade Division

**Includes 528,000 kg valued at $106,000 from South Africa

## PRICES (33)

U.S. kyanite is sold in raw and calcined forms. Raw kyanite prices are between U.S. $70 and $137/t, whereas calcined kyanite is between U.S. $123 and $172/t. The price for bulk

shipments of 59 to 62% $Al_2O_3$, minus 420 plus 44 $\mu$m, raw/calcined, in 16.5 t lots is between U.S. $144 and $248.

Sillimanite from South Africa, grading 70% $Al_2O_3$, sells for $300/t. Andalusite from South Africa is sold in two grades: 60% $Al_2O_3$ is about U.S. $200/t, and 57% $Al_2O_3$ about U.S. $150/t.

## CANMET STUDIES

### Background

Eighteen CANMET kyanite beneficiation studies (34-51), and four studies (52-55) by other organizations were reviewed. Two CANMET sillimanite beneficiation studies (56,57), and three CANMET andalusite studies (58-60) were also reviewed. Summaries of CANMET kyanite studies are presented in Appendix 1, and of the four studies by other organizations in Appendix 2. Summaries of CANMET sillimanite studies are presented in Appendix 3, and summaries of the CANMET andalusite studies in Appendix 4.

The summary of each study includes, if known, the original sample weight, head analysis, mineralogy, beneficiation methods, beneficiation product sizes, concentrate grades and recoveries, as well as remarks or observations of particular interest. The original sample weight is indicative of the scale of investigation, whether bench, laboratory, semi-pilot plant or pilot plant. The head analyses provide data concerning the mineral content and whether the sample originates from a high or low-grade deposit. Mineralogical information not only identifies major and minor minerals, but also provides data regarding association between minerals and host rocks. The liberation size in many cases is either not known or not stated; the beneficiation product size is quoted since, by inference, product size under optimum test conditions usually equates to liberation size. Beneficiation methods are important as a guide for future studies of ores with similar mineral assemblages, and concentrate grade and recovery figures provide an indication of how efficient the beneficiation methods were in

achieving a specification product. Data regarding flotation parameter and reagent concentration are also reported. Studies common to a particular deposit, when possible, are grouped together for continuity and convenience of reference.

The kyanite, sillimanite and andalusite studies were conducted by CANMET and its predecessor, Mines Branch, between 1933 and 1987. The majority of kyanite studies were conducted on samples from Ontario and British Columbia. Sillimanite samples were obtained from Ontario and Manitoba, and andalusite samples from Nova Scotia.

A summary of process data for kyanite, sillimanite and andalusite beneficiation studies is reported in Table 9, and of mineralogical analysis data in Table 10.

**Scale**

The feed weight for most studies was less than 140 kg; eight kyanite studies (37-40,43, 45,53,54) were conducted on samples weighing in excess of 1 t.

**Head Analyses**

The analyses for kyanite samples varied widely, from 10.7% kyanite in an ore from Boat Encampment, British Columbia (51) to 96.7% kyanite in ores from the Sudbury area, Ontario (44,46). The analyses for sillimanite samples was less variable, between 20% sillimanite for an ore from Clarendon, Ontario (56) and 30% sillimanite for an ore from Star Lake, Manitoba (57). The head analyses for andalusite samples were much lower, between 7% andalusite (59) and 12% andalusite (58); both samples were from Nova Scotia.

**Mineralogy**

Minerals associated with kyanite, sillimanite and andalusite are those that are usually found with schists and gneisses. These minerals include quartz, feldspar, sericite, muscovite,

## Table 9 - Summary of Process Data for Kyanite, Sillimanite and Andalusite Beneficiation Studies

| Deposit location | Lot No. | Sample wt (kg) | Process methods | Ref. No. |
|---|---|---|---|---|
| **Kyanite** | | | | |
| Temiskaming, Que. | 1 | 91 | magnetic separation | 34 |
| Butler twp., Ont. | 1 | 139 | magnetic separation, grinding, flotation, PCE evaluation | 35 |
| Butler twp., Ont. | 1 | 1.8 t | magnetic separation, grinding, desliming, flotation | 36 |
| Claridon, Ont. | 1 | 5 | crushing, screening, magnetic separation, flotation | 37 |
| Mattawa, Ont. | 1 | 36 | crushing, magnetic separation, flotation | 38 |
| Mattawa, Ont. | 1 | 2 t | grinding, air classification, magnetic separation, flotation, tabling | 39 |
| Mattawa, Ont. | 1 | 1.8 t | crushing, grinding, magnetic separation, air tabling | 40 |
| Mattawa, Ont. | 1 | n.s. | grinding, desliming, flotation | 41 |
| | 2 | n.s. | grinding, desliming, flotation | 41 |
| Mattawa, Ont. | 1 | n.s. | grinding, dry pressing, drying, firing | 42 |
| Mattawa, Ont. | 1 | n.s. | dry pressing, hardening, firing, PCE evaluation, load testing, thermal expansion | 43 |
| Sudbury, Ont. | 1 | n.s. | grinding, dry pressing, drying, firing | 42 |
| Sudbury, Ont. | 1 | n.s. | dry pressing, hardening, firing, PCE evaluation, load testing, thermal expansion | 43 |
| Sudbury, Ont. | 1 | 1.4 t | crushing, sizing, magnetic separation, jigging, tabling, flotation | 44 |
| Sudbury, Ont. | 1 | n.s. | crushing, screening, dry classification, flotation, magnetic separation | 45 |
| Sudbury, Ont. | 1 | n.s. | crushing, screening, air tabling, flotation, magnetic separation | 46 |
| Dryden twp., Ont. | 1 | 2.3 t | crushing, grinding, screening, magnetic separation, wet jigging, air tabling | 47 |
| Dryden twp., Ont. | 1 | 5 t | magnetic separation, grinding, flotation | 48 |
| Dryden twp., Ont. | 1 | 75 | crushing, screening, magnetic separation, jigging, flotation | 52 |
| Dryden twp., Ont. | 2 | 70 | crushing, screening, magnetic separation, jigging, flotation | 52 |
| Dryden twp., Ont. | 1 | 4.5 t | crushing, screening, magnetic separation, jigging, flotation | 53 |
| Dryden twp., Ont. | 1 | 9 t | crushing, screening, jigging, magnetic separation, grinding, tabling | 54 |
| Death Rapids, B.C. | 1 | n.s. | firing, microscopic crystal examination | 49 |
| Death Rapids, B.C. | 1 | 30 | crushing, screening, grinding, flotation | 50 |
| Boat Encampment, B.C. | 1 | 64 | crushing, screening, magnetic separation, air tabling, flotation | 51 |
| Albreda, B.C. | 1 | 14 | grinding, hydrosizing, magnetic separation, agglomerate tabling, flotation | 55 |
| **Sillimanite** | | | | |
| Clarendon, Ont. | 1 | 7 | crushing, screening, air classification, magnetic separation | 56 |
| Star Lake, Man. | 1 | 10 | crushing, screening, magnetic separation, air classification, flotation | 57 |
| **Andalusite** | | | | |
| Nova Scotia | 1 | 50 | crushing, screening, magnetic separation, flotation | |
| Nova Scotia | 1 | 90 | too low grade for processing | |
| Guysboro cnty., N.S. | 1 | 90 | too low grade for processing | |

n.s. - not specified

## Table 10 - Summary of Mineralogical Analysis Data for Kyanite, Sillimanite and Andalusite Beneficiation Studies

| Deposit location | Lot No. | Head analysis, % | | | | Product % | | Ref. No. |
|---|---|---|---|---|---|---|---|---|
| | | S.G.M.[1] | Mica[2] | Qtz.[3] | Iron[4] | S.G.M. grade | S.G.M. rec. | |
| **Kyanite** | | | | | | | | |
| Butler twp., Ont. | 1 | 11.5 | n.s. | n.s. | n.s. | 95.0 | - | 35 |
| Butler twp., Ont. | 1 | 14.5 | 45.9 | 25.2 | 14.3 | 91.4 | - | 36 |
| Claridon, Ont. | 1 | <10.0[5] | 85.0[5] | - | n.s. | 61.0 | 51.9 | 37 |
| Mattawa, Ont. | 1 | 55.4 | 33.8 | - | 10.8 | 94.0 | 83.4 | 38 |
| Mattawa, Ont. | 1 | 13.0 | n.s. | n.s. | n.s. | 90.7 | 74.1 | 39 |
| Mattawa, Ont. | 1 | 11.3 | 27.0 | - | tr | - | - | 40 |
| Mattawa, Ont. | 1 | 24.0 | tr | - | - | 92.6 | 71.1 | 41 |
| | 2 | 12.0 | n.s. | - | - | 90.7 | 74.1 | 41 |
| Mattawa, Ont. | 1 | 94.0 | tr | tr | tr | n.a. | n.a. | 42 |
| Mattawa, Ont. | 1 | 94.0 | tr | tr | tr | n.a. | n.a. | 43 |
| Sudbury, Ont. | 1 | 96.7 | tr | tr | tr | n.a. | n.a. | 42 |
| Sudbury, Ont. | 1 | 96.7 | tr | tr | tr | n.a. | n.a. | 43 |
| Sudbury, Ont. | 1 | 30.0 | n.s. | - | n.s. | 95.0 | - | 44 |
| Sudbury, Ont. | 1 | 20.0 | 40.0 | n.s. | n.s. | 96.8 | 79.6 | 45 |
| Sudbury, Ont. | 1 | 20.0 | 40.0 | n.s. | n.s. | 95.0 | n.s. | 46 |
| Dryden twp., Ont. | 1 | 19.8 | 35.4 | 41.0 | 3.8 | 85.0[5] | n.s. | 47 |
| Dryden twp., Ont. | 1 | 20.0[5] | n.s. | n.s. | n.s. | 94.0 | 85.0 | 48 |
| Dryden twp., Ont. | 1 | 25.0 | n.s. | n.s. | n.s. | 95.0 | n.s. | 52 |
| | 2 | 15.0 | n.s. | n.s. | n.s. | 95.0 | n.s. | 52 |
| Dryden twp., Ont. | 1 | 21.1 | 26.1 | 29.3 | 23.0 | 96.8 | n.s. | 53 |
| Dryden twp., Ont. | 1 | 23.1 | 26.1 | 27.8 | 22.5 | 87.2[5] | n.s. | 54 |
| Death Rapids, B.C. | 1 | 95.0 | tr | tr | - | - | - | 49 |
| Death Rapids, B.C. | 1 | n.s. | - | n.s. | - | 97.7 | 58.2 | 50 |
| Boat Encampment, B.C. | 1 | 10.7 | 47.1 | 23.8 | 14.1 | 92.6 | 85.3 | 51 |
| Albreda, B.C. | 1 | 17.0 | 8.0 | 55.0[5] | 15.0 | 95.0 | 50.0 | 55 |
| **Sillimanite** | | | | | | | | |
| Clarendon, Ont. | 1 | 20.0 | n.s. | n.s. | n.s. | 56.0 | n.s. | 56 |
| Star Lake, Man. | 1 | 30.0 | 9.0 | 60.0 | tr | 64.4 | 64.0 | 57 |
| **Andalusite** | | | | | | | | |
| Nova Scotia | 1 | 12.0 | - | 65.0[5] | 19.0 | 45.0 | n.s. | 58 |
| Nova Scotia | 1 | 7.0 | 55.0 | 30.0 | tr | n.a. | n.a. | 59 |
| Guysboro cnty., N.S. | 1 | n.s. | n.s. | n.s. | n.s. | n.a. | n.a. | 60 |

[1]Sillimanite-group mineral; analysis for each mineral is reported under the separate mineral headings
[2]Includes all mica minerals but principally muscovite and biotite
[3]Includes quartz and feldspar
[4]Includes all iron oxide minerals, garnet, magnetite, pyrrhotite, pyrite and hornblende
[5]Estimated; n.a. not applicable; n.s. not specified; tr trace

biotite, hornblende, staurolite, tourmaline, graphite, garnet, magnetite, pyrite, pyrrhotite, rutile and ilmenite.

**Analysis Methods**

The sillimanite-group minerals possess the same chemical composition, $Al_2O_3.SiO_2$, and are usually associated with other alumino-silicate minerals, so that $\%Al_2O_3$ is only an indication of chemical purity. The degree of purity of these minerals is usually determined mineralogically, since each possesses a distinct and different crystal habit. Kyanite is characterized by crystal aggregates with radiating or interlocking structure and long-bladed forms; andalusite by square prisms or massive radiating forms; and sillimanite by fine, needle-shaped crystals.

**Beneficiation**

The same beneficiation techniques were used to concentrate kyanite, sillimanite and andalusite samples. These included magnetic separation to remove iron-bearing minerals such as garnet, magnetite and pyrrhotite, and flotation to increase the final grade to specification level. Kyanite, because of its relatively high specific gravity (3.6 to 3.7), was also beneficiated by gravity concentration. The techniques employed included wet jigging (38,43,52-54), wet tabling (38,39,54,55), air tabling (40,43,48,51), and air classification (39,47,56,57).

The various beneficiation techniques successfully concentrated kyanite samples in most studies to >90% kyanite. Sillimanite samples were concentrated to between 56.0 and 64.4% sillimanite (56,57), whereas andalusite samples were too low grade to achieve any meaningful levels of concentration.

Flotation was used to concentrate all three minerals, and since flotation involves the optimization of many parameters, this technique is discussed separately.

**Flotation**

The flotation response of the sillimanite-group minerals is basically similar for each mineral, which is to be expected since each is chemically the same. The majority of flotation tests were conducted with kyanite, so that only kyanite flotation is discussed, although the noted flotation behaviour applies equally to andalusite and sillimanite. A summary of principal parameter data is reported in Table 11, reagent concentration data for rougher flotation in Table 12, and reagent concentration data for cleaner flotation in Table 13.

Kyanite floated between pH 4.2 (42) and pH 9.2 (45) using either oleic acid or Neo Fat 142 (a fatty acid derivative). Anionic flotation is the preferred route because of the presence of quartz which is floated by cationic collectors. Alkali pH values are preferred to acid pH values because some iron minerals occurring with kyanite are partially soluble in an acid medium. This results in ferric ions being released into solution and precipitating oleate collectors which, in turn, reduces kyanite recovery.

The effects of other parameters in kyanite flotation are not very different from standard alumino-silicate mineral flotation conditions. Kyanite flotation is fairly fast, between 5 and 8 min (47,50), multi-stage cleaning is necessary for specification-grade, and a fairly coarse grind of minus 420 $\mu$m (48) is usually necessary.

A typical test, performed by Wyman (45), resulted in a grade of 94% kyanite with recoveries of 85% after three stages of cleaning. A collector concentration of 1000 g/t oleic acid modified with sodium carbonate at pH 9.2 was used with 100 g/t sodium silicate to depress quartz.

The modifiers and depressants used included sodium hydroxide, sodium carbonate, sodium silicate, lactic acid and quebracho. Sodium hydroxide and sodium carbonate were used as pH modifiers. Sodium silicate acted as a slime dispersant and a quartz depressant; it also hindered the precipitation of calcium soaps from hard water and so promoted the formation

**Table 11 - Summary of Principal Parameter Data for Kyanite Flotation Studies**

| Deposit location | Rougher | | | Cleaner | | | Ref. No. |
|---|---|---|---|---|---|---|---|
| | Grind size µm | Pulp density % solids | pH | Float time min | No. of cleaning stages | Float time min/stage | |
| **Kyanite** | | | | | | | |
| Butler twp., Ont. | 100% - 210 | n.s. | 4.8 | n.s. | 3 | n.s. | 35 |
| Butler twp., Ont. | 100% - 250 | n.s. | 5.0 | n.s. | 5 | n.s. | 36 |
| Claridon, Ont. | -300 + 150 | n.s. | 4.2 | n.s. | 2 | n.s. | 37 |
| Mattawa, Ont. | -300 | n.s. | 4.7 | n.s. | 1 | n.s. | 38 |
| Mattawa, Ont. | -300 | n.s. | 4.6 | n.s. | 1 | n.s. | 41 |
| | -300 | n.s. | 4.3 | n.s. | 3 | n.s. | 41 |
| Sudbury, Ont. | -600 + 210 | n.s. | n.s. | n.s. | n.s. | n.s. | 44 |
| Sudbury, Ont. | -300 | 18 | 9.0 | 8 | 3 | 3.3 | 45 |
| Sudbury, Ont. | -420 | n.s. | 9.0 | n.s. | 3 | n.s. | 46 |
| Dryden twp. Ont. | n.s. | 25 | 9.2 | n.s. | 3 | n.s. | 48 |
| | n.s. | 20 | 9.2 | n.s. | 3 | n.s. | 48 |
| Death Rapids, B.C. | n.s. | n.s. | n.s. | 5 | 1 | 5 | 50 |
| Boat Encampment, B.C. | -300 | n.s. | n.s. | n.s. | 1 | n.s. | 51 |
| **Sillimanite** | | | | | | | |
| Star Lake, Man. | n.s. | 30 | 9.7 | 18 | 2 | 5.0 | 57 |

n.s. - not specified

**Table 12 - Summary of Reagent Concentration Data for Kyanite and Sillimanite Rougher Flotation Studies**

| Deposit location | Lot No. | Collectors | | Modifiers | | | | | Ref. No. |
|---|---|---|---|---|---|---|---|---|---|
| | | Oleic acid g/t | Neo Fat 142 g/t | Lactic acid g/t | Quebracho g/t | $Na_2SiO_3$ g/t | $Na_2CO_3$ g/t | NaOH g/t | |
| **Kyanite** | | | | | | | | | |
| Butler twp., Ont. | 1 | 450 | - | - | - | - | - | - | 35 |
| Butler twp., Ont. | 1 | 450 | - | - | - | - | - | - | 36 |
| Claridon, Ont. | 1 | 250 | - | 100 | - | - | - | - | 37 |
| Mattawa, Ont. | 1 | 350 | - | - | 100 | - | - | - | 39 |
| Mattawa, Ont. | 1 | - | 850 | 100 | - | - | - | - | 41 |
| | 2 | - | 1000 | 100 | - | - | - | - | 41 |
| Sudbury, Ont. | 1 | 750 | - | - | - | 100 | 250 | - | 45 |
| Sudbury, Ont. | 1 | 750 | - | - | - | 100 | - | - | 46 |
| Death Rapids, B.C. | 1 | 350 | - | - | - | - | 2000 | - | 50 |
| Boat Encampment, B.C. | 1 | - | 900 | 50 | - | - | - | - | 51 |
| **Sillimanite** | | | | | | | | | |
| Star Lake, Man. | 1 | 470 | - | - | - | - | - | 500 | 57 |

**Table 13 - Summary of Reagent Concentration Data for Kyanite and Sillimanite Cleaner Flotation Studies**

| Deposit location | Lot No. | Collectors | | Modifiers | | | | | Ref. No. |
|---|---|---|---|---|---|---|---|---|---|
| | | Oleic acid g/t | Neo Fat 142 g/t | Lactic acid g/t | Queb* g/t | $Na_2SiO_3$ g/t | $Na_2CO_3$ g/t | NaOH g/t | |
| **Kyanite** | | | | | | | | | |
| Butler twp., Ont. | 1 | - | - | 150 | - | - | - | - | 35 |
| Butler twp., Ont. | 1 | 200 | - | 250 | - | - | - | - | 36 |
| Claridon, Ont. | 1 | 200 | - | 100 | - | - | - | - | 37 |
| Mattawa, Ont. | 1 | - | - | - | 125 | - | - | - | 39 |
| Mattawa, Ont. | 1 | - | 200 | 100 | - | - | - | - | 41 |
| | 2 | - | 300 | 300 | - | - | - | - | 41 |
| Boat Encampment, B.C. | 1 | - | 250 | 50 | - | - | - | - | 51 |
| **Sillimanite** | | | | | | | | | |
| Star Lake, Man. | 1 | - | - | - | - | - | - | 400 | 57 |

* Quebracho

and stabilization of froths. Sodium hydroxide also acted as a slime dispersant, and sodium carbonate had an inhibiting effect on quartz flotation. Lactic acid was used to depress muscovite, and quebracho to depress carbonaceous material.

## Ceramic Evaluation

The successful attainment of specification-grade kyanite was followed by ceramic evaluation for some samples (36,46). A standard procedure for ceramic evaluation involved dry pressing, hardening, firing, pyrometric cone evaluation, load testing and thermal expansion.

## CONCLUDING COMMENT

This report is the tenth in a Summary Report series on industrial minerals. These reports are designed to assist individuals or companies having an interest in industrial minerals in Canada. A wide distribution of the Summary Report series is planned as a means of encouraging interest in the further development of industrial minerals for use in many diverse applications, from fillers for everyday products such as paint and rubber to the high-technology sector for products such as high-performance plastics.

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# APPENDIX 1

# SUMMARIES OF CANMET KYANITE STUDIES

## QUEBEC

| | | |
|---|---|---|
| Identification | : | Que.-1 (Ref. No. 34) |
| Report - Title | : | BENEFICIATION OF KYANITE FROM NARCO MINES LIMITED, TEMISKAMING |
| - Author | : | F.H. Hartman |
| - No. and Date | : | *Industrial Minerals Report* (unnumbered) (1970) |
| Sample Description | : | A 91 kg sample of thickener underflow, kyanite concentrate containing graphite and abraded mill iron. |
| Objective | : | To remove iron before grinding for ceramic refractory evaluation. |
| Processing | : | Magnetic separation to remove magnetic material using the Jones high intensity, wet magnetic separator. A sample of non-magnetic material unground, and a non-magnetic sample ground to minus 44 $\mu$m, were the final products for evaluation. |
| Results | : | The iron analysis of the unground non-magnetic fraction was lower, at 0.15% Fe, than that reported for the ground non-magnetic product, at 0.55% Fe. |
| Potential Use | : | Not determined. |

## ONTARIO

| | | |
|---|---|---|
| Identification | : | Ont.-1 (Ref. No. 35) |
| Report - Title | : | BATCH FLOTATION TESTS AND PILOT-MILL RUN ON SHIPMENTS OF KYANITE ORE FROM J.J. KENMEY, NORTH BAY: PART 1 - LABORATORY TESTWORK |
| - Author | : | H.L. Beer |
| - No. and Date | : | *Industrial Minerals Report (Preliminary)* 136 (1952) |
| Sample Description | : | A 139 kg sample of kyanite ore from Butler township analyzing 11.5% kyanite, associated with garnet, biotite and muscovite. Pre-concentration to remove magnetic material increased the kyanite grade to about 30%. |
| Objective | : | To establish flotation parameters for the production of high-grade kyanite in a subsequent pilot-plant run. |
| Processing | : | Grinding to minus 210 $\mu$m, followed by flotation of first mica, then kyanite. A portion of high-grade kyanite concentrate, analyzing 95%, was subjected to pyrometric cone equivalent determination for kyanite purity assessment. |
| Results | : | Flotation produced a high-grade muscovite concentrate, and, a high-grade kyanite concentrate analyzing 95%. The recovery, however, was not optimized. Ceramic evaluation showed a value of >Cone 35 (1,785°C) which indicated a high degree of purity. |
| Potential Use | : | Not applicable. |

| | | |
|---|---|---|
| Identification | : | Ont.-2 (Ref. No. 36) |
| Report - Title | : | BATCH FLOTATION TESTS AND PILOT-MILL RUN ON SHIPMENTS OF KYANITE ORE FROM J.J. KENMEY, NORTH BAY: PART 2 - PILOT MILL RUN |
| - Author | : | H.L. Beer |
| - No. and Date | : | *Industrial Minerals Report (Preliminary)* 136 (1952) |
| Sample Description | : | A 1.8 t sample of kyanite ore from Butler township analyzing 14.5% kyanite, 14.3% garnet, 27.4% muscovite, 18.5% biotite, and 25.2% quartz and feldspar. Pre-concentration to remove garnet, biotite and muscovite increased the kyanite grade to 34%. |
| Objective | : | To produce high-grade kyanite. |
| Processing | : | Grinding to minus 250 $\mu$m, followed by desliming in a hydroseparator. The classifier underflow was conditioned and subjected to flotation. Flotation involved removal of muscovite followed by flotation of kyanite. |
| Results | : | A kyanite concentrate analyzing 91.4% kyanite was obtained after five stages of cleaning. The recovery was, however, low because of fine-grained biotite, which caused a significant amount of kyanite to remain unfloated. |
| Potential Use | : | Not determined. |

| | | |
|---|---|---|
| Identification | : | Ont.-3 (Ref. No. 37) |
| Report - Title | : | FLOTATION CONCENTRATION OF A SAMPLE OF KYANITE ORE FROM THE PROPERTY OF STRATEGIC METALS LIMITED, CLARIDON |
| - Author | : | H.L. Beer |
| - No. and Date | : | *Industrial Minerals Report* 206 (1953). |
| Sample Description | : | A 5 kg sample of low-grade kyanite ore consisting mainly of mica and biotite with a minor amount of kyanite and pyrite. |
| Objective | : | To produce high-grade kyanite. |
| Processing | : | Crushing by rolls crusher to minus 300 $\mu$m and screening to remove the minus 150 $\mu$m. The minus 300 plus 150 $\mu$m fraction was subjected to magnetic separation to remove magnetic material. The non-magnetic fraction was further beneficiated by flotation of pyrite, followed by mica and, finally, kyanite. |
| Results | : | A concentrate analyzing 61% kyanite with a recovery of 51.9% was obtained. |
| Potential Use | : | Too low-grade for refractory use. |

| | | |
|---|---|---|
| Identification | : | Ont.-4 (Ref. No. 38) |
| Report - Title | : | CONCENTRATION TESTS ON A SAMPLE OF 'HIGH GRADE' KYANITE ORE FROM MATTAWA |
| - Author | : | H.L. Beer |
| - No. and Date | : | *Ore Dressing Investigation Report* (unnumbered) (1952) |
| Sample Description | : | A 36 kg sample of high-grade kyanite ore from Butler township analyzing 55.4% kyanite, 33.8% muscovite and 10.8% pyrrhotite. |
| Objective | : | To produce a high-grade, 90% kyanite concentrate. |
| Processing | : | Crushing to 210 $\mu$m, followed by dry magnetic separation to remove pyrrhotite. Remaining sulphide material and muscovite were removed by flotation leaving an enriched kyanite concentrate as the flotation tailings. |
| Results | : | A kyanite concentrate analyzing >94% was obtained with a recovery of 83.4%. |
| Potential Use | : | Possibly suitable for refractory use. |

| | | |
|---|---|---|
| Identification | : | Ont.-5 (Ref. No. 39) |
| Report - Title | : | BATCH CONCENTRATION TESTS ON KYANITE ORE FROM KYANITE CORPORATION OF CANADA, MATTAWA |
| - Author | : | H.L. Beer |
| - No. and Date | : | *Industrial Minerals Report* 163 (1953) |
| Sample Description | : | A 2 t sample of kyanite ore consisting of kyanite, muscovite, feldspar, quartz, pyrite, biotite and garnet. The original kyanite analysis was 13%; pre-concentration prior to flotation increased kyanite to 60%. |
| Objective | : | To produce a high-grade, 90% kyanite concentrate. |
| Processing | : | Grinding to 840 $\mu$m, followed by air classification to remove minus 300 $\mu$m material. The minus 840 plus 300 $\mu$m fraction was passed through a dry, high intensity magnetic separator to remove biotite and garnet. Further beneficiation involved grinding to minus 300 $\mu$m, followed by either flotation or wet tabling. The sequence of flotation was pyrite, muscovite followed by kyanite. |
| Results | : | Flotation produced a concentrate analyzing 90.7% kyanite with a recovery of 74.1%. Wet tabling produced a concentrate analyzing 92.9% kyanite with a recovery of 44.6%. |
| Potential Use | : | Possibly refractory-grade kyanite. |

| | | |
|---|---|---|
| Identification | : | Ont.-6 (Ref. No. 40) |
| Report - Title: | : | REPORT ON MILL RUN OF KYANITE SAMPLE FROM THE GOLWYNNE CHEMICAL COMPANY PROPERTY, MATTAWA |
| - Author | : | V.A. Haw |
| - No. and Date | : | *Industrial Minerals Report* 183 (1953) |
| Sample Description | : | A 1.82 t sample of kyanite ore analyzing 11.3% kyanite and 27% muscovite, with accessory garnet. |
| Objective | : | To compare the centre peripheral discharge rod mill with the Pennsylvania impact crusher. |
| Processing | : | Crushing to minus 40 mm, followed by comparative grinding in a centre peripheral discharge rod mill, and a Pennsylvania impact crusher. Further beneficiation was conducted using the impact crusher as it was superior in delaminating muscovite, and in minimizing the production of minus 600 $\mu$m fines. Garnet was removed by magnetic separation of the plus 600 $\mu$m, and minus 600 plus 300 $\mu$m fractions. The very fine dust was removed from the minus 300 $\mu$m fraction by air classification before passing the sized product through the magnetic separator. The non-magnetic fractions were then passed over a Kipp-Kelly air table to remove muscovite. |
| Results | : | The impact crusher produced a better ground product than the peripheral discharge rod mill. Garnet and muscovite were successfully separated in subsequent beneficiation studies. |
| Potential Use | : | Not applicable. |

| | | |
|---|---|---|
| Identification | : | Ont.-7 (Ref. No. 41) |
| Report - Title | : | FLOTATION TESTS ON SAMPLES 'N' FROM THE KYANITE CORPORATION OF CANADA, MATTAWA |
| - Author | : | H.L. Beer |
| - No. and Date | : | *Industrial Minerals Report* 185 (1953) |
| Sample Description | : | Two samples of kyanite ore associated with pyrite, biotite, muscovite and quartz. Sample 1, an air table concentrate from which most of the muscovite had been removed, analyzed about 24% kyanite. Sample 2, which contained most of the original muscovite, analyzed about 12% kyanite. Magnetic material had been removed from each sample. |
| Objective | : | To produce high-grade kyanite concentrates. |
| Processing | : | Wet grinding to pass 300 $\mu$m, followed by desliming and flotation. Flotation involved removal of pyrite, followed by muscovite and, finally, kyanite. |
| Results | : | A kyanite concentrate from Sample 1 material analyzed 92.6% kyanite, and represented a recovery of 71.1%. A kyanite concentrate from Sample 2 material analyzed 90.7% kyanite, and represented a recovery of 74.1%. |
| Potential Use | : | Possibly suitable for refractory use. |

| | | |
|---|---|---|
| Identification | : | Ont.-8 (Ref. No. 42) |
| Report - Title | : | CANADIAN KYANITE AS A REFRACTORY RAW MATERIAL FOR THE PRODUCTION OF HIGH-GRADE REFRACTORY PRODUCTS: PART 1 - DEVELOPMENT OF REFRACTORY AGGREGATE |
| - Author | : | V.D. Svikis |
| - No. and Date | : | *Industrial Minerals Research Report* 168 (1954) |
| Sample Description | : | A 91% and 94% kyanite concentrate from Mattawa, Ontario, and a 96.7% kyanite concentrate from Sudbury, Ontario. |
| Objective | : | To improve the properties of fired Canadian kyanite products by introducing additives into the body compositions. |
| Processing | : | Grinding to pass 75 $\mu$m, followed by mixing with various additives. Each specimen mix was dry-pressed using a laboratory hydraulic press, followed by drying in an infrared dryer at 70°C for 4 to 6 h. The firing was carried out in a Remney-type, gas-fired laboratory furnace. |
| Results | : | Certain types of aluminum phosphates (Alkophos B) were highly effective in producing volume-stable and dense-refractory aggregates. The results indicated that in order to produce a volume-stable and dense-refractory aggregate with a porosity $<10\%$, 5 to 8% of Alkophos B was required. The forming pressure should not be $<5600$ t.m$^{-2}$, and the formed briquette should be calcined at 1600°C, and maintained at that temperature for 2 to 5 h. |
| Potential Use | : | Possibly suitable for refractory use. |

| | | |
|---|---|---|
| Identification | : | Ont.-9 (Ref. No. 43) |
| Report - Title | : | CANADIAN KYANITE AS A REFRACTORY RAW MATERIAL FOR THE PRODUCTION OF HIGH-GRADE REFRACTORY PRODUCTS: PART 2 - THE FORTIFICATION OF REFRACTORY AGGREGATE |
| - Author | : | V.D. Svikis |
| - No. and Date | : | *Industrial Minerals Research Report* 212 (1956) |
| Sample Description | : | A 91% and 94% kyanite concentrate from Mattawa, Ontario, and a 96.7% kyanite concentrate from Sudbury, Ontario. |
| Objective | : | To improve the properties of fired Canadian kyanite products by introducing phosphoric acid mineralizer, and increasing the alumina content. |
| Processing | : | Minus 44 $\mu$m kyanite concentrate, and alumina in the ratio of 4:1 were mixed with tempering water (6%) and phosphoric acid (4%), dry-pressed at 7,000 $t.m^{-2}$ and, after hardening, fired for 3 h at 1650°C and 1700°C. The parameters were varied, but the above values were considered representative. Other testing included pyrometric cone equivalent, thermal expansion, and load testing at high temperatures. |
| Results | : | It was found that the addition of alumina to the kyanite concentrate together with small amounts of phosphoric acid as the mineralizer, make possible the production of an aggregate having refractory properties superior to those obtainable from kyanite alone. At the same time, a high degree of stability and density can be maintained by making some adjustment in one or more of the several other variables, namely: percentage addition of phosphoric acid, fineness of grind, forming pressure and firing temperature. |
| Potential Use | : | Possibly suitable for refractory use. |

| | | |
|---|---|---|
| Identification | : | Ont.-10 (Ref. No. 44) |
| Report - Title | : | CONCENTRATION OF KYANITE ORE FROM THE HOYLE MINING COMPANY, SUDBURY |
| - Author | : | H.L. Beer |
| - No. and Date | : | *Industrial Minerals Research Report* 161 (1953) |
| Sample Description | : | A 1360 kg sample of pre-concentrated kyanite ore analyzing 30% kyanite, obtained near Sudbury. |
| Objective | : | To produce high-grade, 90% kyanite. |
| Processing | : | Prior concentration involved crushing and sizing to produce a minus 1.2 mm plus 210 $\mu$m fraction, which was further upgraded by magnetic separation to remove biotite and garnet. Further beneficiation included jigging, tabling and flotation. |
| Results | : | Jigging produced a concentrate analyzing 55 to 60% kyanite with a recovery of 75%. Tabling produced a slightly better grade concentrate at 65 to 70% kyanite for a recovery of about 60%. Flotation of the minus 600 plus 210 $\mu$m fraction produced a 95% grade kyanite concentrate. |
| Potential Use | : | Possibly suitable for refractory use. |

| | | |
|---|---|---|
| Identification | : | Ont.-11 (Ref. No. 45) |
| Report - Title | : | HIGHLIGHTS OF LABORATORY TESTWORK PERFORMED ON A KYANITE-BEARING GNEISS FROM THE SUDBURY PROPERTY OF NORTHERN KYANITE MINES LIMITED |
| - Authors | : | R.A. Wyman and W.J.D. Stone |
| - No. and Date | : | *Investigation Report* 58-165 (1958) |
| Sample Description | : | A sample of a kyanite-bearing gneiss analyzing about 20% kyanite, 40% biotite, with garnet, quartz and feldspar comprising the remainder. Liberation size was established at 600 $\mu$m. |
| Objective | : | To establish parameters for pilot plant testwork. |
| Processing | : | The techniques that were employed in removing biotite and concentrating kyanite included screening, jigging, wet and dry tabling, cone classification, flotation and magnetic separation. Each technique by itself was only partially successful.<br><br>The best flowsheet for producing high grade and high recovery of kyanite consisted of crushing, with screening and classification at 300 $\mu$m. Coarse, plus 300 $\mu$m biotite was removed by this technique. The minus 300 $\mu$m fraction was subjected to cationic flotation to remove biotite and quartz. Kyanite was floated using a fatty acid collector and final beneficiation to remove biotite was by magnetic separation. |
| Results | : | A kyanite concentrate analyzing 96.8% kyanite with a recovery of 79.6% was obtained. |
| Potential Use | : | Possibly suitable for refractory use. |

| | | |
|---|---|---|
| Identification | : | Ont.-12 (Ref. No. 46) |
| Report - Title | : | HIGHLIGHTS OF PILOT PLANT TESTWORK PERFORMED ON A KYANITE-BEARING GNEISS FROM THE SUDBURY PROPERTY OF NORTHERN KYANITE MINES LIMITED |
| - Authors | : | R.A. Wyman and W.J.D. Stone |
| - No. and Date | : | *Investigation Report* 58-165 (1958) |
| Sample Description | : | The same as for the previous investigation. |
| Objective | : | To produce a high-grade product for ceramic evaluation. |
| Processing | : | Crushing to pass 1.7 mm, followed by screening to produce minus 1.7 mm plus 420, minus 420 plus 210 $\mu$m, minus 210 plus 150 $\mu$m, and minus 150 $\mu$m fractions. Air tabling was used to beneficiate the plus 210 $\mu$m fractions, and flotation for the minus 210 plus 150 $\mu$m fraction. The float feed was deslimed by a hydroclassifier and kyanite floated using a fatty acid collector. Final upgrading of the kyanite concentrate, from each method, was by magnetic separation. |
| Results | : | 2.5 t of kyanite concentrates analyzing 95% kyanite were produced for ceramic evaluation. |
| Potential Use | : | Possibly suitable for refractory use. |

| | | |
|---|---|---|
| Identification | : | Ont.-13 (Ref. No. 47) |
| Report - Title | : | PROGRESS REPORT - INVESTIGATION OF METHODS FOR RECOVERY OF KYANITE FROM SAMPLES SUBMITTED BY THE HOYLE MINING COMPANY LIMITED |
| - Author | : | V.A. Haw |
| - No. and Date | : | *Industrial Minerals Report* 295 (1954) |
| Sample Description | : | A 2.3 t sample of a kyanite-garnet-biotite schist from Dryden township, analyzing 19.8% kyanite, 41.0% quartz and feldspar, 35.4% biotite and 3.8% garnet. |
| Objective | : | To produce high-grade kyanite concentrates. |
| Processing | : | Crushing to pass 19 mm, followed by grinding in a centre peripheral discharge rod mill to pass 420 $\mu$m. The ground product was sized to give minus 420 plus 210 $\mu$m and, minus 210 $\mu$m fractions. The minus 210 $\mu$m fraction was air classified to remove very fine dust. Each fraction was passed through a dry magnetic separator to remove biotite and garnet. Further beneficiation of the non-magnetic portion of the minus 420 plus 210 $\mu$m fraction was carried out by wet jigging and air tabling. |
| Results | : | Garnet and biotite were successfully removed by magnetic separation. Subsequent beneficiation concentrated kyanite, but grade did not exceed 90%. |
| Potential Use | : | Not applicable. |

| | | |
|---|---|---|
| Identification | : | Ont.-14 (Ref. No. 48) |
| Report - Title | : | LABORATORY AND PILOT PLANT FLOTATION STUDIES ON A KYANITE ORE FROM THE SUDBURY AREA |
| - Author | : | R.A. Wyman |
| - No. and Date | : | *Industrial Minerals Research Report* 189 (1955) |
| Sample Description | : | A 5 t sample of minus 420 plus 75 $\mu$m pre-concentrated kyanite ore. The biotite and garnet had been removed by magnetic separation. The pre-concentrated ore analyzed about 32% kyanite, with quartz and feldspar accounting for the remaining minerals. The sample was obtained from Dryden township. |
| Objective | : | To produce about 1 t of high-grade, 94% kyanite. |
| Processing | : | Process parameters for flotation were optimized on a laboratory basis, so that production of a bulk concentrate could be obtained on a pilot-plant scale. |
| Results | : | A concentrate analyzing 94% or better was obtained with a recovery of 85%. |
| Potential Use | : | Not determined. |

## BRITISH COLUMBIA

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|---|---|---|
| Identification | : | B.C.-1 (Ref. No. 49) |
| Report - Title | : | REFRACTORY EVALUATION OF KYANITE FROM DEATH RAPIDS |
| - Author | : | J.F. McMahon |
| - No. and Date | : | *Unpublished Results* (1933) |
| Sample Description | : | A sample of kyanite analyzing >95% kyanite, concentrated by flotation, details of which were reported in a previous study. |
| Objective | : | To evaluate kyanite for refractory use. |
| Processing | : | Heating to convert kyanite to mullite ($3Al_2O_3.2SiO_2$), followed by microscopic examination to study the conversion effect upon the crystal structures. |
| Results | : | The kyanite displayed similar properties to standard refractory kyanites. The decrease in specific gravity, upon conversion to mullite, was from 3.62 to 3.04. Specimens containing 88 to 98% kyanite showed linear expansions of 8 to 16%. Microscopic examination indicated that upon burning, the material maintained its original platy structure to a marked extent. There was, however, some difficulty in developing binders for the calcined material. |
| Potential Use | : | Suitable for use as a refractory product. |

| | | |
|---|---|---|
| Identification | : | B.C.-2 (Ref. No. 50) |
| Report - Title | : | THE CONCENTRATION OF KYANITE FROM DEATH RAPIDS |
| - Author | : | R.K. Carnochan |
| - No. and Date | : | *Ore Dressing Investigation Report* 472 (1933) |
| Sample Description | : | A 30 kg sample of kyanite ore which consisted of long, flat, sky-blue crystals of kyanite in a white quartz matrix. |
| Objective | : | To produce a kyanite concentrate suitable for refractory use. |
| Processing | : | Crushing 45 kg to pass 25 mm, followed by screening to produce minus 25 plus 12.5 mm, and minus 12.5 plus 6.3 mm fractions from which kyanite was hand-picked. The remaining 15 kg head sample was crushed to pass 840 $\mu$m. A 500 g portion was ground to an unspecified size and subjected to flotation to produce a high-grade kyanite concentrate. |
| Results | : | Flotation produced a concentrate analyzing 97.7% kyanite for a recovery of 58.2%. |
| Potential Use | : | Possibly suitable for refractory use. |

| | | |
|---|---|---|
| Identification | : | B.C.-3 (Ref. No. 51) |
| Report - Title | : | REPORT ON THE SAMPLE OF KYANITE FROM THE YELLOW CREEK MICA COMPANY LIMITED |
| - Author | : | V.A. Haw |
| - No. and Date | : | *Industrial Minerals Report* 178 (1953) |
| Sample Description | : | A 64 kg sample of lump kyanite-garnet-mica gneiss. The kyanite crystals measured up to 12 mm in length, and rounded red crystals of garnet were up to 6.3 mm in size. The muscovite was fine-grained. The mineralogical analysis was 10.7% kyanite, 20.1% muscovite, 27% biotite, 14.1% garnet, 23.8% quartz and 4.3% staurolite. The sample was from Boat Encampment on the Big Bend of the Columbia River. |
| Objective | : | To produce high-grade kyanite. |
| Processing | : | Crushing to minus 840 $\mu$m, followed by screening to produce plus 300 $\mu$m, and minus 300 plus 150 $\mu$m fractions. Each fraction was passed through the Exolon dry magnetic separator to separate staurolite, garnet and biotite. The non-magnetic portions of each fraction were passed over a Kipp Kelly air table to remove muscovite. The partially beneficiated kyanite concentrate (50% kyanite) was then ground to pass 300 $\mu$m, followed by flotation of first mica, then kyanite. |
| Results | : | A kyanite concentrate analyzing 92.6% kyanite with a recovery of 85.3% was obtained. |
| Potential Use | : | Possibly suitable for refractory use. |

# APPENDIX 2

# SUMMARIES OF KYANITE STUDIES BY OTHER ORGANIZATIONS

## ONTARIO

| | | |
|---|---|---|
| Identification | : | Ont.-15 (Ref. No. 52) |
| Report - Title | : | BENEFICIATION OF KYANITE SCHIST FOR THE HOYLE MINING COMPANY LIMITED |
| - Author | : | E.O. Foster |
| - No. and Date | : | *Lakefield Research Report* (1952) |
| Sample Description | : | Two samples of kyanite schist designated "Perry" (Sample 1), and "Chubb" (Sample 2). Sample 1 weighed 75 kg and contained about 25% kyanite. Sample 2 weighed 70 kg and contained about 15% kyanite. The chief gangue minerals intimately associated with kyanite were biotite, muscovite, feldspar, quartz and garnet. |
| Objective | : | To produce high-grade kyanite for distribution to prospective consumers. |
| Processing | : | Crushing to pass 420 $\mu$m, followed by screening to produce minus 420 plus 210 $\mu$m, minus 210 plus 70 $\mu$m, and minus 70 $\mu$m fractions. The first two fractions were treated by magnetic separation which removed all of the garnet, most of the biotite, and some of the muscovite. The non-magnetic, minus 420 plus 210 $\mu$m fraction, was further beneficiated by wet jigging. The non-magnetic, minus 210 plus 70 $\mu$m fraction, was further beneficiated by flotation. The jig concentrate was ground to minus 300 $\mu$m, and finally upgraded by flotation. |
| Results | : | Concentrates produced from Sample 1 and Sample 2 material analyzed about 95% kyanite. |
| Potential Use | : | Possibly suitable for refractory use. |

| | | |
|---|---|---|
| Identification | : | Ont.-16 (Ref. No. 53) |
| Report - Title | : | BENEFICIATION OF KYANITE SCHIST FROM THE DRYDEN TOWNSHIP KYANITE DEPOSIT OF THE HOYLE MINING COMPANY |
| - Author | : | E.O. Foster |
| - No. and Date | : | *Lakefield Research Report* (1953) |
| Sample Description | : | A 4.5 t sample of a kyanite-mica schist, which consisted of kyanite occurring as medium-fine, long bladed, blue crystals. The mineralogical analysis was 21.1% kyanite, 13.2% feldspar, 16.1% quartz, 26.1% biotite, 23.0% garnet with minor amounts of muscovite and magnetite. |
| Objective | : | To produce high-grade kyanite. |
| Processing | : | Crushing to minus 2.4 mm, followed by screening at minus 2.4 plus 1.2 mm to remove coarse biotite. The minus 1.2 mm product was further sized to produce minus 1.2 mm plus 210 $\mu$m, and minus 210 $\mu$m fractions. Each of the three fractions was passed through a dry magnetic separator to separate biotite and garnet. The minus 1.2 mm plus 210 $\mu$m non-magnetic product was further beneficiated by jigging, and the minus 210 $\mu$m non-magnetic portion by flotation. |
| Results | : | Jigging produced a grade of 90.5% kyanite, and flotation a grade of 96.84%. Recoveries, however, were not optimized. |
| Potential Use | : | Possibly suitable for refractory use. |

| | | |
|---|---|---|
| Identification | : | Ont.-17 (Ref. No. 54) |
| Report - Title | : | BENEFICIATION OF KYANITE SCHIST FOR THE HOYLE MINING COMPANY LIMITED: PILOT PLANT EVALUATION |
| - Author | : | E.O. Foster |
| - No. and Date | : | *Lakefield Research Report* (1954) |
| Sample Description | : | A 9 t sample of kyanite schist obtained from Dryden township which analyzed 23.1% kyanite, 10.6% feldspar, 17.2% quartz, 26.1% mica and 22.5% garnet. Trace minerals included muscovite and magnetite. |
| Objective | : | To determine whether kyanite could be recovered at a coarse size of about 1.2 mm. |
| Processing | : | Crushing to minus 1.2 mm, followed by screening to produce minus 1.2 mm plus 840 $\mu$m, minus 840 plus 420 $\mu$m, minus 420 plus 210 $\mu$m, and minus 210 plus 75 $\mu$m fractions. The plus 210 $\mu$m fractions were each treated separately by wet jigging. The concentrates were further upgraded by magnetic separation.<br><br>A second portion of feed material was crushed to minus 6.3 mm, and ground to minus 600 $\mu$m. The ground product was wet tabled to remove mica, and the table concentrate further upgraded by jigging. The jig concentrate was dried, and finally upgraded by magnetic separation. |
| Results | : | A coarse, 1.2 mm kyanite concentrate analyzing 80.8% kyanite and a fine, 600 $\mu$m kyanite concentrate analyzing 93.6% kyanite, were produced. Thus high-grade kyanite could not be obtained at 1.2 mm size. |
| Potential Use | : | Not determined. |

## BRITISH COLUMBIA

| | | |
|---|---|---|
| Identification | : | B.C.-4 (Ref. No. 55) |
| Report - Title | : | RECOVERY OF KYANITE FROM KYANITE SCHIST, NORTH THOMPSON RIVER: PROGRESS REPORT NO. 1 |
| - Author | : | J.M. Cummings |
| - No. and Date | : | *University of British Columbia Report, Project* O.D. 10 (1943) |
| Sample Description | : | A 14 kg sample of kyanite schist obtained from the vicinity of Albreda. The sample analyzed about 17% kyanite, 15% garnet, 8% biotite, with major quartz and feldspar; minor rutile and tourmaline accounted for the remainder. |
| Objective | : | To produce high-grade kyanite suitable for ceramic evaluation. |
| Processing | : | Grinding to 93% minus 600 $\mu$m, and hydroclassified to produce seven spigot products, a slime, and a plus 600 $\mu$m fraction. Each spigot product was tabled separately to produce a kyanite-garnet concentrate, which was passed through a medium intensity magnetic separator to remove garnet. The non-magnetic portion was sized to produce a plus 410 $\mu$m, and minus 410 $\mu$m fraction. The coarse fraction was further beneficiated by agglomerate tabling and the fine fraction by flotation. Rutile and tourmaline were removed from the concentrates by passing through a high intensity magnetic separator. |
| Results | : | A combined concentrate analyzing 95% kyanite and representing 50% recovery was obtained. Ceramic evaluation indicated no fusion at cone 33 and the test pieces were of a good white colour. |
| Potential Use | : | Possibly suitable for refractory use. |

# APPENDIX 3

# SUMMARIES OF CANMET SILLIMANITE STUDIES

## ONTARIO

| | | |
|---|---|---|
| Identification | : | Ont.-1 (Ref. No. 56) |
| Report - Title | : | A PRELIMINARY STUDY OF THE BENEFICIATION OF A SAMPLE OF SILLIMANITE FROM CLARENDON |
| - Authors | : | P.R.A. Andrews and W. Kelly |
| - No. and Date | : | *Division Report* 87-167 (IR) (1987) |
| Sample Description | : | Pelitic porphyroblastic schist with a matrix displaying good foliation. The 20% sillimanite crystals exhibited aspect ratios between 20:1 and 30:1. The major portion consisted of quartz, plagioclase feldspar and magnetite, with minor biotite and muscovite. Sillimanite liberation was at 300 $\mu$m. |
| Objective | : | Filler or refractory use. |
| Processing | : | Crushing to 600 $\mu$m, sizing to produce minus 600 plus 300 $\mu$m, minus 300 plus 150 $\mu$m fractions, with removal of minus 150 $\mu$m fines. Comparison of air classification followed by magnetic separation, with magnetite separation followed by air classification. |
| Results | : | The best results were obtained for the minus 600 plus 300 $\mu$m fraction using air classification before magnetic separation. A product analyzing 56% sillimanite was obtained, but with a low recovery. |
| Potential Use | : | Possible filler use. |

## MANITOBA

| | | |
|---|---|---|
| Identification | : | Man.-1 (Ref. No. 57) |
| Report - Title | : | SEPARATION OF GARNET AND SILLIMANITE FROM AN ANTHOPHYLLITE GNEISS, OBTAINED FROM STAR LAKE |
| - Author | : | P.R.A. Andrews |
| - No. and Date | : | *Division Report* 87-121 (IR) (1987) |
| Sample Description | : | A sample of quartz-sillimanite gneiss consisting of 60% quartz, 30% sillimanite, 9% biotite and phlogopite, with minor garnet. |
| Objective | : | Filler or refractory use. |
| Processing | : | Crushing and sizing to produce a minus 2.5 mm plus 630 $\mu$m fraction, followed by magnetic separation to separate biotite. Air classification was used to separate the non-magnetic biotite-phlogopite phase, and flotation to separate sillimanite from quartz. |
| Results | : | A concentrate analyzing 64.4% sillimanite was obtained with a recovery of 64%. |
| Potential Use | : | Possibly suitable for filler use as the aspect ratio was between 10:1 and 15:1. |

# APPENDIX 4

# SUMMARIES OF CANMET ANDALUSITE STUDIES

## NOVA SCOTIA

| | | |
|---|---|---|
| Identification | : | N.S.-1 (Ref. No. 58) |
| Report - Title | : | CONCENTRATION OF ANDALUSITE FROM A SAMPLE OF NOVA SCOTIA SCHIST |
| - Author | : | R.A. Wyman |
| - No. and Date | : | *Industrial Minerals Report* 501 (1958) |
| Sample Description | : | A 50 kg sample of sericitic and siliceous schist with metacrysts analyzing about 15% garnet, 12% andalusite and 4% magnetite, with trace hornblende. |
| Objective | : | Refractory use. |
| Processing | : | Crushing to 1.2 mm, and sizing to 210 $\mu$m, followed by magnetic separation of the minus 420 plus 150 $\mu$m fraction to remove magnetite and garnet, with final upgrading by flotation. |
| Results | : | Magnetite and garnet were separated, but andalusite was only partially concentrated by flotation. The feed to flotation was 45% andalusite. |

| | | |
|---|---|---|
| Identification | : | N.S.-2 (Ref. No. 59) |
| Report - Title | : | REPORT ON THE BULK SAMPLE OF ANDALUSITE ORE |
| - Author | : | V.A. Haw |
| - No. and Date | : | *Industrial Minerals Report* 255 (1954) |
| Sample Description | : | A 90 kg sample of fine-grained greenish-grey ore exhibiting some schistosity and analyzing about 45% muscovite, 30% quartz, 10% biotite and 7% andalusite, with minor pyrrhotite and iron oxides. |
| Processing | : | Too low-grade to warrant beneficiation. |

| | | |
|---|---|---|
| Identification | : | N.S.-3 (Ref. No. 60) |
| Report - Title | : | REPORT ON INVESTIGATIONS OF AN ANDALUSITE SCHIST FROM GUYSBORO COUNTY |
| - Author | : | V.A. Haw |
| - No. and Date | : | *Industrial Minerals Report* 283 (1954) |
| Sample Description | : | A 50 kg sample of fine-grained knotted schist, dark-grey in appearance, principally consisting of schist material with minor andalusite, magnetite and ilmenite. |
| Processing | : | Considered too low-grade for processing. |